AD-A035 208 CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAI--ETC F/G 5/1
ENGINEERING AND DESIGN PERFORMANCE ANALYSIS.(U)
DEC 76 R L LAPP, J G KIRBY

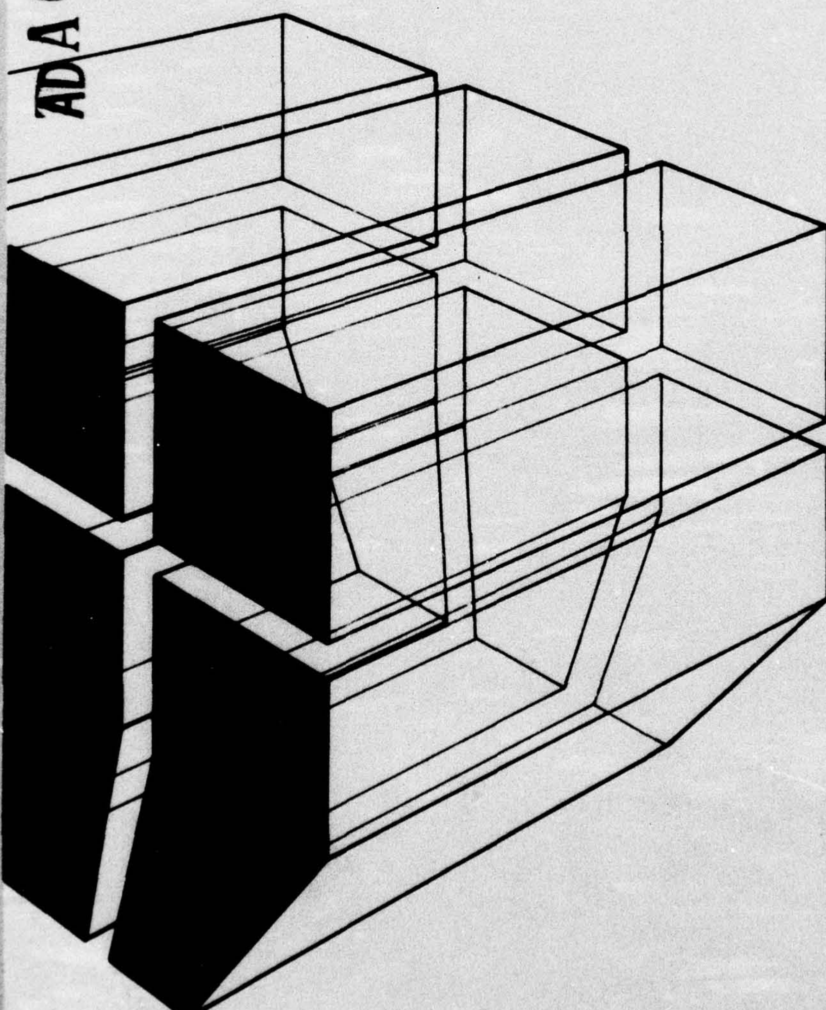
UNCLASSIFIED CERL-IR-C-75 NL

1 OF 4
AD
A035208

construction
engineering
research
laboratory

INTERIM REPORT C-75
December 1976
Improved Engineering and Design Performance

ENGINEERING AND DESIGN PERFORMANCE ANALYSIS



by
R. L. Lapp
J. G. Kirby

CERL

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER INTERIM REPORT C-75	2. GOVT ACCESSION NO. 14 CERL-IR-C-75	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 ENGINEERING AND DESIGN PERFORMANCE ANALYSIS.		5. TYPE OF REPORT & PERIOD COVERED 9 INTERIM rept., 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Roger L. Lapp Jeffrey G. Kirby		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. Box 4005 Champaign, Illinois 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 4K0780120K1-03-010
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 11 December 1976 13. NUMBER OF PAGES 314 12 316p.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are obtainable from National Technical Information Service, Springfield, VA 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

general activity network
preconstruction design
advertisement and award data

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Corps of Engineers design process has been represented by a general activity network of 127 quantifiable activities: 13 for environmental impact statements, 30 for architect-engineer (A/E) procurement and District Engineer predesign, 53 for preconstruction design, 13 for advertisement and award, and 18 for design modification activities. → Next pg.

405 279

bpg

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Five bodies of project time and cost were identified. Detailed project data from the Fort Worth District have been completely analyzed: two sets of data were partially analyzed (ER 415-345-43 project data and MIDAS project data); advertisement and award data were received but not analyzed; and a satisfactory source for design modification (during construction) data is being sought.

FOREWORD

This study was performed by the U.S. Army Construction Engineering Research Laboratory (CERL) under RDT&E Project 4K078012OK1, "Engineering Criteria for Design and Construction," Task 03, "Applications of Construction Methods," Work Unit 010, "Improved Engineering and Design Performance." The applicable Requirement Code is QCR 1.04.001. Work was performed under the technical direction of the Office of the Chief of Engineers, Directorate of Military Construction. Mr. Peter J. Van Parys was the OCE Technical Monitor.

Work was conducted by the Facility Systems Branch (Richard J. Colver, Chief) of the Facility Operations Division (Robert Blackmon, Chief).

Extensive contributions of the following people are gratefully acknowledged: Mr. David W. Brown, CERL; personnel of the Engineering Divisions of the U.S. Army Engineer Districts at Savannah and Fort Worth; and Dr. Mohamed Dessouky of CERL.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

FIGURES

FIGURES (cont'd)

FIGURES (cont'd)

TABLES

TABLES (cont'd)

TABLES (cont'd)

ENGINEERING AND DESIGN PERFORMANCE ANALYSIS

1 INTRODUCTION

Purpose

The purpose of this report is to evaluate the Army military construction engineering and design process in order to determine where improvements might be made. Improved performance is measured in terms of maintenance of design and construction schedules and in terms of the resultant design quality and cost.

Scope

This study embraces both out-of-house (Architect-Engineer [A/E]) and in-house (District forces) design. A/E design is emphasized, since the major portion of Army design work is contracted. The major aspects of the process examined are the environmental impact statement (if any), the A/E procurement and District office predesign activities, concept (or preliminary) and final design, advertisement and award, and design modifications.

Background

In the past, several studies have been made of the design process or its aspects; these studies have usually had a qualitative emphasis. Since the qualitative approach yields a definition of the process structure, known problem areas can be evaluated if this information is supplemented with quantitative data.

Corps Studies

Two comprehensive, largely qualitative studies[1,2] about the Corps of Engineers' approach to design have resulted in positive recommendations. For example, the recommendation for computer-based specifications preparation has been recognized and is now currently under development.

---

[1] D. R. Drew, et al., *Investigation and Study of Corps of Engineers System Approach to Design and Construction for Military Construction*, Technical Report 68-041/AD840174 (Texas A&M Research Foundation, May 1968).
[2] P. T. McCoy and C. R. Sprague, *Systems Analysis of Corps/A-E Design Engineering*, Technical Report 69-041/AD865247 (Texas A&M Research Foundation, June 1969).

Other Significant Studies

A 1970 study revealed that the GSA sequential contracting method required a 59-month design and construction time for major building projects, compared to 24 months for similar projects in the private sector. Many factors influenced the time discrepancy, but phased construction,[3] in which final design and construction would be concurrent, was a promising solution to this problem.

However, another study[4] conducted by the Air Force that appears to conflict with this GSA theory suggests that a single procurement-design-construction approach may not be applicable under all circumstances. The Air Force study found no statistically significant project completion time differences among the three procurement methods used by government agencies: the conventional, two-step, and design and build (turnkey) methods. The conventional and two-step methods were found to be significantly cheaper statistically than the turnkey method, which allows, but does not presuppose, phased construction.

Complexity

The Army's overall engineering and design process is so complex that one person would be unable to understand all the activities that comprise and influence it. The enormity of the process and the necessity for individual specialization complicate the task of collecting evaluation data.

Current design process definition and analysis is a trial-and-error procedure. Initially, activity networks (sequences) of various design phases are hypothesized from readily available information. Based on these hypotheses, data are acquired on the activities themselves (times and costs). Invariably, the raw data must be edited and re-edited before processing. After processing, the hypothesized network must be altered to conform to the latest available information. Results of analyzing different data bodies which apply to the same activity must be reconciled. These foregoing actions must be recycled until a reasonably coherent and comprehensive picture of the entire design process emerges. Then the process should be computer-programmed to allow economical analysis of different project types and project management methods.

---

[3] *The GSA System for Construction Management*, revised edition, Technical Report GSA DC 75-9492 (General Services Administration, April 1975).

[4] G. D. Smith and D. A. Krausse, *A Study to Determine If Design and Build Procurement Methods for Military Family Housing Are More Economical Than Conventional or Two Step Methods*, Technical Report SLSR-28-72B/AD750919 (Air Force Institute of Technology, September 1972).

Workload

The Army's design workload is approximately $80 million annually; military construction work placement is approximately 20 times the FY76 design expenditure ($1.568 billion). The design work force, including support personnel, is about 3000 persons; approximately 2000 projects are being actively designed concurrently.

Approach

The basic approach of this study has been to gather and evaluate information about the design process, emphasizing quantification whereever possible. Broadly, the design process structure encompasses design methodology and management--but structure, methodology, and management are treated as separate features of this study, as shown below:

1. Design Process Structure Evaluation

    Design data collection

    Design activities definition, existence and sequence

    Design data analysis, activity time and cost scaling

    Design process modeling, integrating activities

    Design process analysis, operating the model, interpreting results

2. Design Methodology Trends Evaluation

3. Design Management Trends Evaluation.

Three criteria enter into the evaluations: quality, cost, and time. Design quality should simply and accurately meet user (constructor and owner) requirements. The cost of a certain quality of work should be calculable and minimal with respect to total costs of original design, revisions arising from design review, and design modifications during construction. Time, given quality and cost, should be calculable for a design project and its individual activities. To avoid the consequences of rescheduling, realistic due dates are very important. Delays not only affect a project's time and cost, but necessitate the rescheduling of other projects. Rescheduling invariably involves slippage, affecting not only design itself, but also procurement, construction, and the owner-user.

Design Data Collection

The intent of data collection for this study was to gather for subsequent analysis *all* available information having reasonably inexpensive acquisition cost. The data collection consisted of two main

efforts that were often closely related. One was the determination of activities and their sequence; the other was the determination of activities' times and costs. Environmental impact statement activities and time estimates were obtained from the Construction Engineering Research Laboratory (CERL). Initially, Savannah District furnished networks for A/E procurement, District engineer predesign, and advertisement and award processes information; then, seven Districts and one Division having military design responsibility were asked about the existence, sequence, and duration of these activities. The Fort Worth District furnished considerable information about the design process: 70 projects were defined in terms of the time and cost expended to conduct 48 active design activities (12 for each of four active design phases: study, preliminary, early final, and final); 285 projects were defined with respect to time needed for nine design periods (four active, three delay, two review) and for advertisement and award.

Data collected were analyzed and are presented in Tables 1 through 4. Certain Corps offices furnished A/E procurement and DE predesign data in a different format. These data have been carefully analyzed and included in the survey results where possible. For certain A/E procurement and DE predesign actions, data supplied by Mobile District was in marked excess of the data supplied by the other Districts. Because of a possible misunderstanding in data interpretation, the out-of-range Mobile District data have been omitted from the tabulated survey results. The survey results may be used for individual Districts and Divisions for self-evaluation and comparison purposes.

Design Activities Definition

The overall design process fits into the framework of the outline shown in Figure 1. This figure, a synopsis of the Military Construction Army (MCA) program presents a broad picture of activities at eight levels of responsibility. Other programs, such as Family Housing, Minor Construction, and Military Construction, Air Force, vary slightly from the MCA pattern. The frame of reference for this study is the process as seen by Corps of Engineers District Offices--the designers who carry out design directives, implement management decisions, and transform plans into reality. The design process was considered to consist of five sequential phases totaling 127 activities: (1) an environmental impact statement process phase of approximately 13 activities, (2) an A/E procurement and District engineer predesign process phase of about 30 activities, (3) a design process phase (preconstruction) of about 53 activities, (4) an advertisement and award phase process of approximately 13 activities, and (5) a design modification process during the construction phase having approximately 18 activities per modification. The activities considered were intended to give a reasonably comprehensive view of the process, without any significant gaps. Necessarily, the kind and number of activities were dependent on the data records kept by District offices (Figure 2). For actions outside the five major District-level design phases at District and other command levels, only those having a major impact on the five District design phases were considered in this study.

Table 1

Activity Time Estimates - A/E Procurement and DE Predesign
Calendar Days Survey Results

Action Number	Actions	Number of Divisions and Districts Responding	Absolute Minimum	Average Minimum	Absolute Maximum	Average Maximum	Average
1	(Dummy start)						
2	Decision, A/E or DE design	3	1	1	30	12	2
3	Review design criteria	6	1	2.0	60	19.3	7.2
4	Determine real estate, relocations	3	0	3.7	30	12.7	7.3
5	Coordination, correspondence	4	3	11.0	60	45.3	15.5
6	(Dummy end)						
7	Predesign conference	7	1	1.4	10	4.8	3.3
8	Determine survey, foundations exploration	4	1	2.0	28	11.0	5.5
9	A/E preselection	7	1	3.0	57	21.7	9.1
10	A/E selection	8	0	3.0	60	25.3	8.1
11	District Engineer, approval of A/E	6	0	2.0	14	8.6	3.3
12	Notify A/E, furnish instructions	8	0	1.2	16	10.2	3.0
13	A/E review of instructions	5	1	3.5	30	14.0	7.2
14	A/E prepare proposal	8	1	3.3	30	20.0	12.1
15	Negotiate A/E contract	8	0	2.5	44	22.0	10.2
16	Prepare A/E instructions	4	1	1.8	59	22.0	5.3
17	Prepare A/E contract	5	1	2.6	45	17.6	9.8
18	Review A/E selection, change if needed	4	1	3.0	7	3.3	2.8
19	District Engineer approval of award	7	0	7.4	45	24.0	10.9
20	Real estate relocations action	2	5	62.5	240	130.5	97.0
21	Update budget sketches, cost estimates	5	1	5.8	30	21.3	12.0
22	Advertise, *Commerce Business Daily*	8	0	14.3	34	25.5	16.3
23	A/E audit by DCAA	7	13	19.4	60	43.6	27.7
24	Division engineer approval of A/E	8	0	6.5	35	17.3	8.9
25	Congressional Notification	3	0	29.7	127.0	62.0	39.0
26	Chief of Engineers approval of A/E	6	1	16.6	42	44.8	32.0
27	Department of Army approval of A/E	5	1	18.8	80	35.0	22.6
28	A/E two step procurement, RFP	1	15		30		20.0
29	A/E delay in notice to proceed	3	1	1.5	60	32.5	11.0
30	A/E or DE, delay in design direction	2	0	0.5	90	60.0	7.5
31	Division engineer approval of award	5	1	8.6	35	18.0	10.4
32	Department of Defense approval of A/E	3	1	22.7	98	44.0	33.0

Table 2

A/E Procurement and DE Predesign Calendar Days Breakdown by Division-District

Action Number	Action	Huntsville			Savannah			New York			Fort Worth			Baltimore		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
1	(Dummy start)															
2	Decision, A/E or DE design				1	5	2	1	30	3	1	1	1			
3	Review design criteria	3	3	3	1	14	4	1	30	5	2	7	2	5	60	20
4	Determine real estate relocations				1	8	2	10	30	20	0	0	0			
5	Coordination, correspondence				3	16	9	15	60	25				15	60	20
6	(Dummy end)															
7	Predesign conference	1	4	3	1	2	1	1	5	1	1	3	1	3	10	5
8	Determine survey, foundations exploration				5	28	15	1	5	1	1	1	1	1	10	5
9	A/E preselection	3	7	4	1	28	5	1	10	5	7	14	7	5	14	10
10	A/E selection	4	20	8	1	14	3	1	14	2	7	14	7	5	30	7
11	District Engineer approval of A/E				1	7	2	1	5	2	7	14	7	1	5	3
12	Notify A/E, furnish instructions	1	4	4	2	14	5	1	10	3	2	7	2	1	10	5
13	A/E review of instructions	3	5	5	3	7	5	1	30	15	7	14	10			
14	A/E prepare proposal	3	30	18	1	5	3	1	30	15	7	14	10	5	14	10
15	Negotiate A/E contract	1	7	4	1	7	1	1	30	10	7	14	7	5	30	15
16	Prepare A/E instructions	4	59	10	1	14	5	1	14	5	1	1	1			
17	Prepare A/E contract	5	10	7	1	2	1	1	30	10	1	1	1	5	45	30
18	Review A/E selection, change if needed				1	1	1	1	2	2	7	7	7			
19	District Engineer approval of award	5	12	9	1	5	2	1	14	5	30	45	30			
20	Real estate relocations action				5	21	14	120	240	180	0	0	0			
21	Update budget sketches, cost estimates				2	30	15	5	15	5	15	30	20	1	10	5
22	Advertise, *Commerce Business Daily*	20	34	22	14	21	18	14	20	17	18	22	18	20	30	25
23	A/E audit by DCAA	13	26	17	21	42	28	21	60	30	42	60	50	20	30	25
24	Division engineer approval of A/E	7	9	4	5	14	10	1	14	7	21	35	21	5	14	10
25	Congressional notification	59	127	79	0	0	0	30	45	38	0	14	0			
26	Chief of Engineers approval of A/E	7	16	13	28	120	90	1	14	7	42	60	42	5	14	10
27	Department of Army approval of A/E	20	46	20	5	15	10	1	20	10	63	80	63	5	14	10
28	A/E two step procurement, RFP				15	30	20									
29	A/E delay in notice to proceed				1	60	30				2	5	2	3	14	10
30	A/E or DE, delay in design directive				1	30	15	0	90	0						
31	Division engineer approval of award	8	12	8	5	15	10	1	14	3	21	35	21	8	14	10
32	Dept. of Defense approval of A/E	59	98	79				1	20	10				8	14	10

Table 2 (cont'd)

Action Number	Action	Sacramento	Omaha	Mobile-Military			Mobile-Civilian		
		Ave.	Ave	Min.	Max.	Ave.	Min.	Max.	Ave.
1	(Dummy start)								
2	Decision, A/E or DE design			0	54	25	1	1	1
3	Review design criteria		9						
4	Determine real estate relocations								
5	Coordination, correspondence		8						
6	(Dummy end)								
7	Predesign conference	10	2	0	280	44	6	34	12
8	Determine survey, foundations exploration			1	289	56	4	45	15
9	A/E preselection		20	1	57	13	10	55	24
10	A/E selection	24	2	0	60	12	0	31	12
11	District Engineer approval of A/E		2	0	12	4	1	10	4
12	Notify A/E, furnish instructions	1	1	0	16	3	0	20	5
13	A/E review of instructions		1						
14	A/E prepare proposal	14	14	3	27	13	1	35	9
15	Negotiate A/E contract	12	2	0	44	10	0	66	12
16	Prepare A/E instructions			1	298	56	4	45	15
17	Prepare A/E contract								
18	Review A/E selection, change if needed	1							
19	District Engineer approval of award	7	2	0	44	21	5	37	17
20	Real estate relocations action								
21	Update budget sketches, cost estimates	15		1	312	65	0	47	21
22	Advertise, *Commerce Business Daily*	5	5	0	24	20	21	21	21
23	A/E audit by DCAA	30	14						
24	Division engineer approval of A/E	8	8	0	18	3	0	12	3
25	Congressional notification								
26	Chief of Engineers approval of A/E		30						
27	Department of Army approval of A/E								
28	A/E two step procurement, RFP								
29	A/E delay in notice to proceed		1						
30	A/E or DE delay in design directive								
31	Division engineer approval of award								
32	Department of Defense approval of A/E								

Table 3

Activity Time Estimates - Advertisement and Award Calendar
Survey Results

Action Number	Actions	Number of Divisions and Districts Responding	Absolute Minimum	Average Minimum	Absolute Maximum	Average Maximum	Average
1	Congressional action, appropriations	3	0	.7	180.	140.0	36.3
2	Scheduling of advertisement and award activities	6	1.	3.5	30.	9.7	5.5
3	Advance notice to bidders	7	1.	10.8	60.	21.7	16.4
4	Government estimate preparation	5	1.	10.6	60.	30.6	5.6
5	Specifications reprocessing (specs section)	6	4.	7.0	21.	14.0	11.8
6	Drawings reprocessing (specs section)	5	1	6.4	21.	12.0	9.0
7	Advertising period	7	15	19.5	90.	60.0	30.4
8	Specifications reproduction	7	2	5.3	21.	11.2	9.4
9	Drawings reproduction	7	1	5.8	21.	13.0	10.1
10	Specifications and drawings amendments	7	1	6.3	50.	20.2	14.1
11	Amendment cutoff period	7	5	8.0	35.	16.0	12.3
12	Pre-award survey, awards board, approvals, etc	7	2	5.8	30.	20.0	10.4

Table 4

Activity Time Estimates - Advertisement and Award
Calendar Days Breakdown by Division-District

Action Number	Actions	Huntsville			Savannah			New York			Fort Worth		
		Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
1	Congressional action, appropriations				2	180	14				0	180	90
2	Scheduling of advertisement and awards activities	2	2	2	5	15	10	1	5	2	1	1	1
3	Advance notice to bidders	30	60	45	1	5	2	3	15	8	14	21	21
4	Government estimate preparation	30	60	45	1	28	10	5	20	14			
5	Specifications reprocessing (specs section)	5	5	5	4	14	8	5	10	7	14	21	21
6	Drawings reprocessing (specs section)	5	5	5	1	4	2	5	10	7	14	21	21
7	Advertising period	30	60	45	15	60	28	15	60	30	21	45	30
8	Specifications reproduction	4	6	5	5	15	10	2	5	3	14	21	21
9	Drawings reproduction	8	10	9	5	15	10	1	5	3	14	21	21
10	Specifications and drawings amendments	20	50	35	5	15	10	1	4	2	3	14	7
11	Amendment cutoff period	10	10	10	5	21	14	7	10	9	11	35	20
12	Pre-award survey, awards board, approvals, etc.	10	20	15	2	20	10	3	15	7	5	30	10

Table 4 (cont'd)

Action Number	Actions	Baltimore			Sacramento			Omaha		
		Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
1	Congressional action, appropriations	0	60	5						
2	Scheduling of advertisement and awards activities	10	30	15	2	5	3			
3	Advance notice to bidders	7	14	10	10	15	15			14
4	Government estimate preparation	2	10	5	10	35	23			
5	Specifications reprocessing (specs section)	7	20	10						20
6	Drawings reprocessing (specs section)	7	20	10						
7	Advertising period	21	90	30	15	45	30			20
8	Specifications reproduction	2	10	7	5	10	6			14
9	Drawings reproduction	2	17	8	5	10	6			14
10	Specifications and drawings amendments	5	30	14	4	8	6			25
11	Amendment cutoff period	10	10	10	5	10	10			13
12	Pre-award survey, awards board, approvals, etc.	7	23	12	8	12	10			9

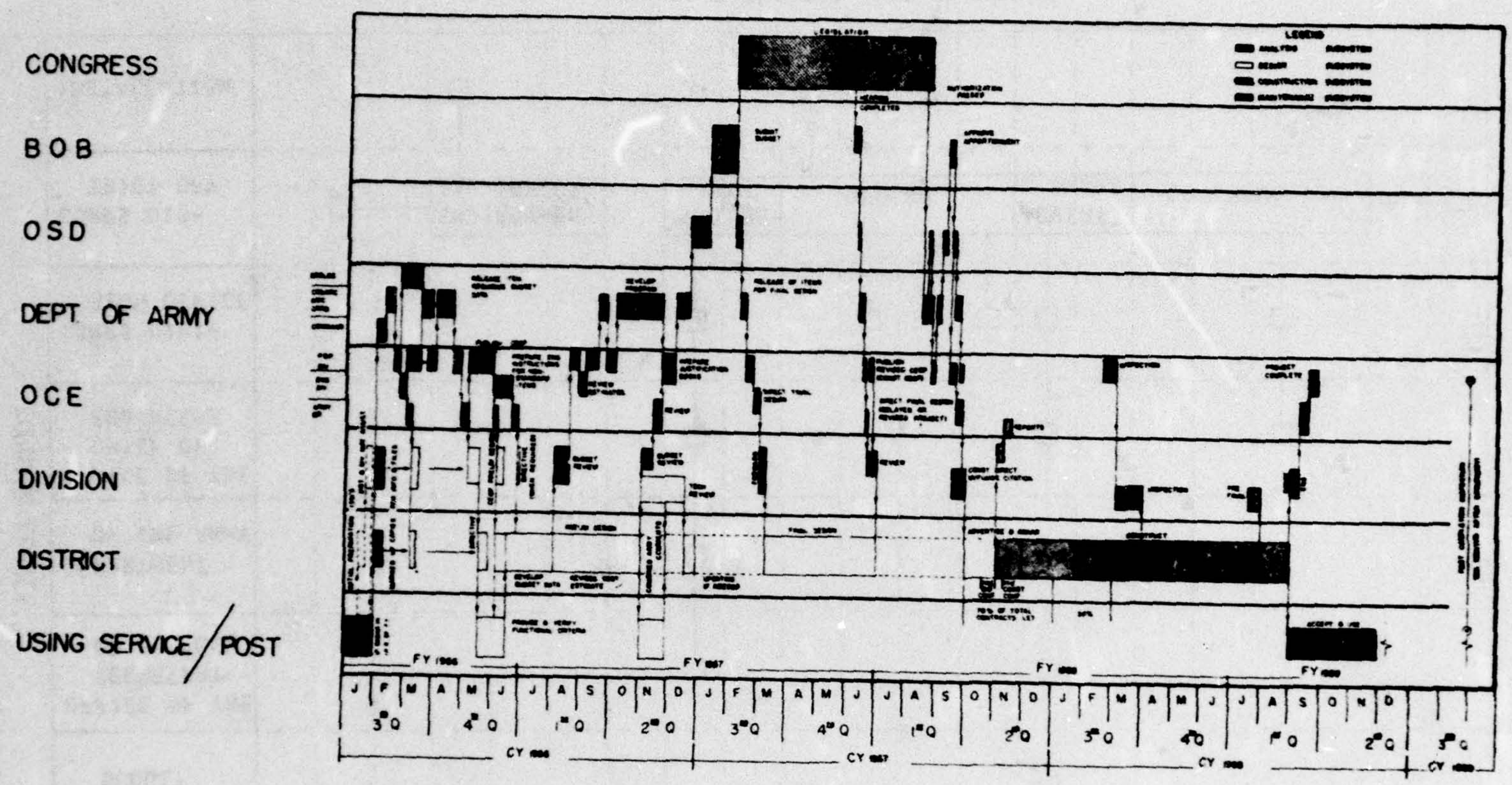


Figure 1. Model of the Army design and construction system.

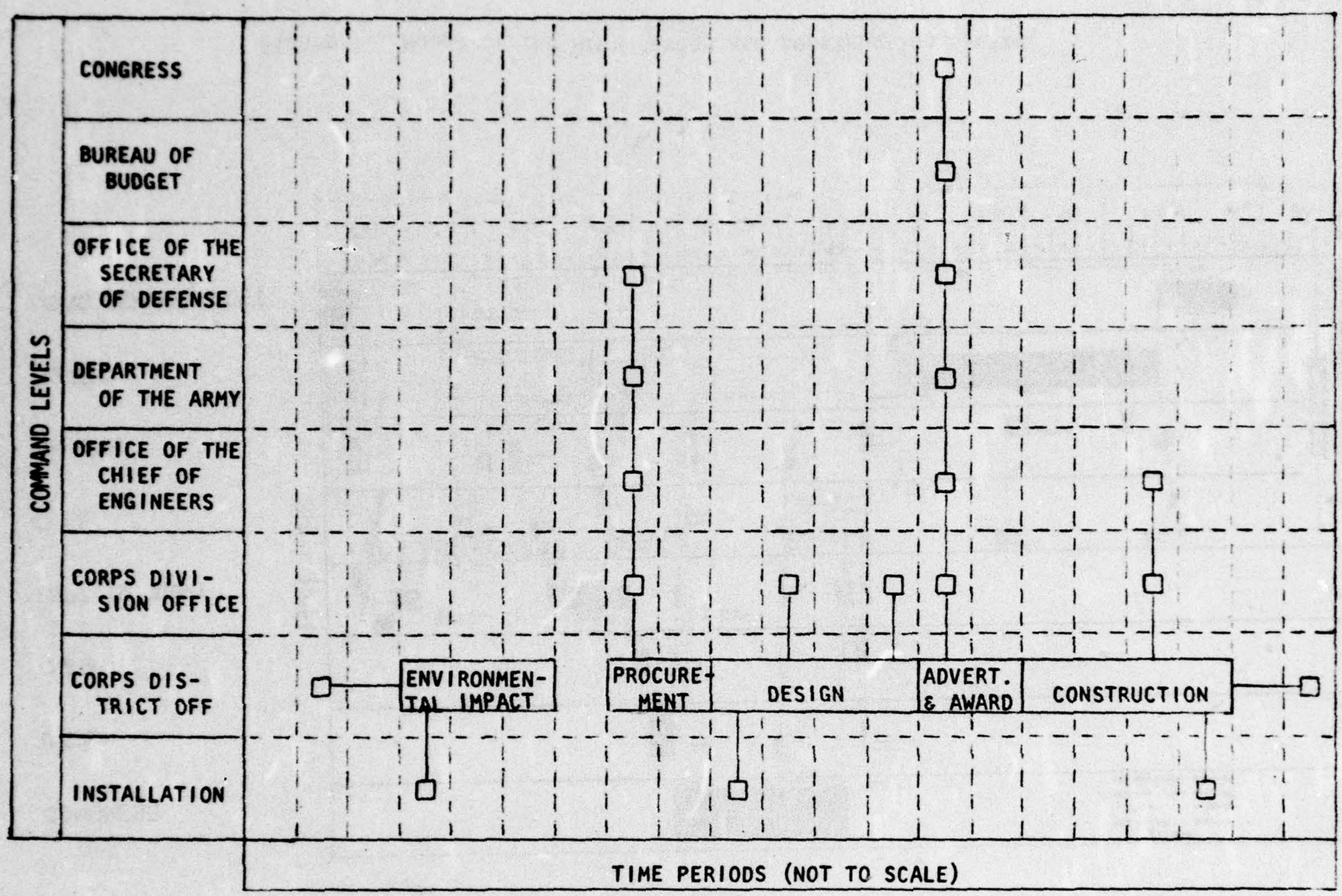


Figure 2. Simplified model of the Army design and construction activities.

Design Data Analysis

Activity time and cost estimate differences are reconciled statistically, and results are expressed in terms of means and standard deviations. Where times and costs were shown or assumed to be interrelated, the relationships were determined by an analytical technique (multiple regression) which uses historical information to predict future outcomes.

Design and Management Methodology Trends

This report focuses on the current design process and on alterations that might be made by management decisions. However, evolving technology (automation) in the various engineering disciplines is certain to significantly affect future design quality, cost, and time. The greatest impact should be on quality. This report discusses both short- and long-term effects.

Management of the design process, which encompasses all activities required to acquire and deploy resources to accomplish the process, is discussed.

Future Studies

Analysis of the Office of the Chief of Engineers' ER 415-345-43 military design and construction progress reporting data base, now about 10,000 projects, has begun. Results of an earlier study of 221 projects evaluated with respect to the design-error/construction-time-overrun relation are available.[5] A satisfactory source for design modifications during construction will be sought. One other District may be able to furnish data corresponding to that of Fort Worth's 285 projects.

An extension of this study will be synthesized into a single general activity network which can simulate many types of design projects. A computer program can represent the network model, operating on both the values of input options that specify the project type, work features, and the values of other input program control variables to solve for activities times and costs. Various levels of input detail can determine networks of corresponding complexity.

[5] D. W. Halpin and R. D. Neathammer, *Construction Time Overruns*, Technical Report P-16/AD766725 (Construction Engineering Research Laboratory [CERL], August 1973).

2 DESIGN ACTIVITY DESCRIPTION AND PRECEDENCE RELATIONSHIPS

Environmental Impact Statement Process

Figure 3 shows a general environmental activity network. An environmental impact assessment (EIA) must be made by a proposing installation when it submits a DD Form 1391, which is a form initiating the procurement process. Therefore, the EIA is not part of the activity network, since its existence is presupposed.

The first activity--preparation--can be broken down as shown in Figure 4; if this level of detail is insufficient, the preparation activities can be broken down to second- and third-level activities, as shown in Table 5. This level of detail will not be formally networked. Table 6 shows a breakdown of the environmental attributes into subattributes. Of the nine possible major Army activities shown in Figure 5[6] (construction; real estate; mission change; operation, maintenance, and repair; training; procurement; industrial activities; research, development, test, and evaluation; and administration and support), only three can ordinarily pertain to a planned project.

An environmental impact statement will be prepared only if requested by an Army installation Director of Facility Engineering or directed by the Office of the Chief of Engineers or by a using agency other than the Army. The impact statement, which precedes formal design, is prepared by the proposing installation. The minimum length of preparation time is 6 months for a simple statement, and 9 months for a complex one. The simple statements will address a limited number of impacting factors and alternatives. Allotted EIA funds will be distributed linearly--90 percent to statement preparation, 10 percent to revision.

A/E Procurement and District Engineer Predesign

Figure 6 shows a general A/E procurement and District Engineer (DE) predesign activity network. Not all of this network's 32 activities (two of which [start and end] are dummies) are applicable to a single project. The method for selecting applicable activities, as given in the decision table of Figure 7, is discussed below. The table can describe 220 different types of networks, which represent all possible actions which are specified by five input conditions (the actions are identified by rules 1-5; 6-13; 14; 15; and 16). Detailed application of the figure is shown below.

[6]R. K. Jain, et al., *Handbook for Environmental Impact Analysis*, Technical Report E-59/ADA006241, September 1974).

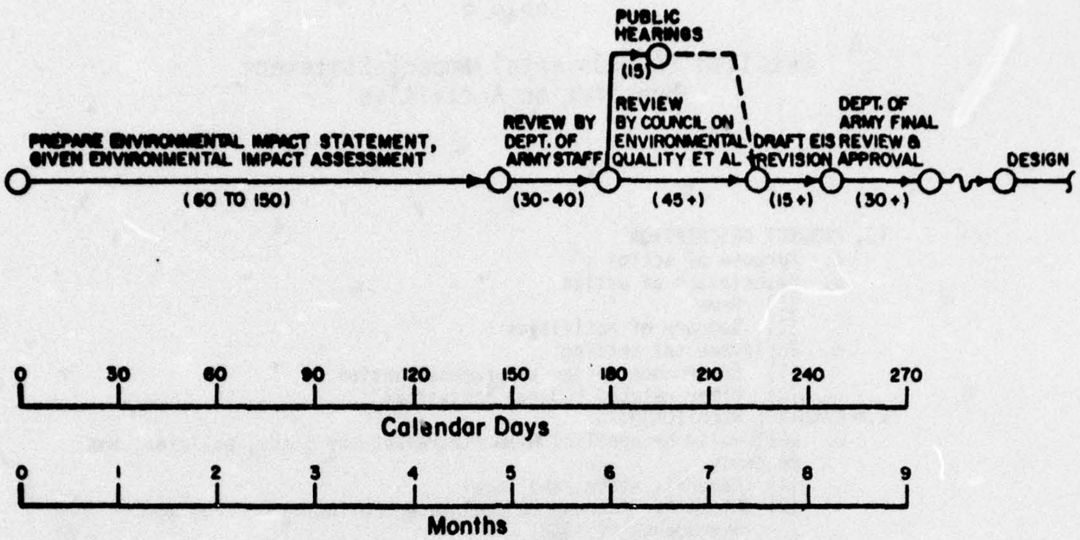


Figure 3. General environmental network.

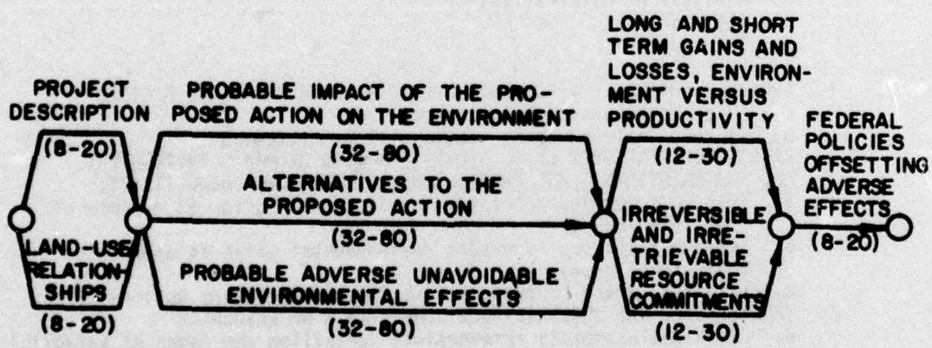


Figure 4. Environmental impact statement preparation network.

Table 5

Detailed Environmental Impact Statement Preparation Activities

1. PROJECT DESCRIPTION
    a. Purpose of action
    b. Description of action
        (1) Name
        (2) Summary of activities
    c. Environmental setting
        (1) Environment prior to proposed action
        (2) Other related Federal activities
2. LAND-USE RELATIONSHIPS
    a. Conformity or conflict with other land-use plans, policies, and controls
        (1) Federal, state, and local
        (2) Clean Air Act and Federal Water Pollution Control Act Amendments of 1972
    b. Conflicts and/or inconsistent land-use plans
        (1) Extent or reconciliation
        (2) Reasons for proceeding with action
3. PROBABLE IMPACT OF THE PROPOSED ACTION OF THE ENVIRONMENT
    a. Positive and negative effects
        (1) National and international environment
        (2) Environmental factors
        (3) Impact of proposed action
    b. Direct and indirect consequences
        (1) Primary effects
        (2) Secondary effects
4. ALTERNATIVES TO THE PROPOSED ACTION
    a. Reasonable alternative actions
        (1) Those that might enhance environmental quality
        (2) Those that might avoid some or all adverse effects
    b. Analysis of alternatives
        (1) Benefits
        (2) Costs
        (3) Risks
5. PROBABLE ADVERSE ENVIRONMENTAL EFFECTS WHICH CANNOT BE AVOIDED
    a. Adverse and unavoidable impacts
    b. How avoidable adverse impacts will be mitigated
6. RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY
    a. Trade-off between short-term environmental gains at expense of long-term losses
    b. Trade-off between long-term environmental gains at expense of short-term losses
    c. Extent to which proposed action forecloses future options
7. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES
    a. Unavoidable impacts irreversibly curtailing the range of potential uses of the environment
        (1) Labor
        (2) Materials
        (3) Natural
        (4) Cultural
8. OTHER INTERESTS AND CONSIDERATIONS OF FEDERAL POLICY THAT OFFSET THE ADVERSE ENVIRONMENTAL EFFECTS OF THE PROPOSED ACTION
    a. Countervailing benefits of proposed action
    b. Countervailing benefits of alternatives

Table 6

Detailed Environmental Attributes

Air	**Ecology**
Diffusion factor	Large animals (wild and domestic)
Particulates	Predatory birds
Sulphur oxides	Small game
Hydrocarbons	Fish, shell fish, and water fowl
Nitrogen oxide	Field crops
Carbon monoxide	Threatened species
Photochemical oxidants	Natural land vegetation
Hazardous toxicants	Aquatic plants
Odor	
	Sound
Water	Physiological effects
Aquifer safe yield	Psychological effects
Flow variations	Communication effects
Oil	Performance effects
Radioactivity	Social behavior effects
Suspended solids	
Thermal pollution	**Socioeconomic**
Acid and alkali	Human
Biochemical oxygen demand	Life styles
Dissolved oxygen (DO)	Psychological needs
Dissolved solids	Physiological systems
Nutrients	Community needs
Toxic compounds	Economic
Aquatic life	Regional economic stability
Fecal coliform	Public sector revenue
	Per capita consumption
Land	
Erosion	
Natural hazard	
Land-use patterns	

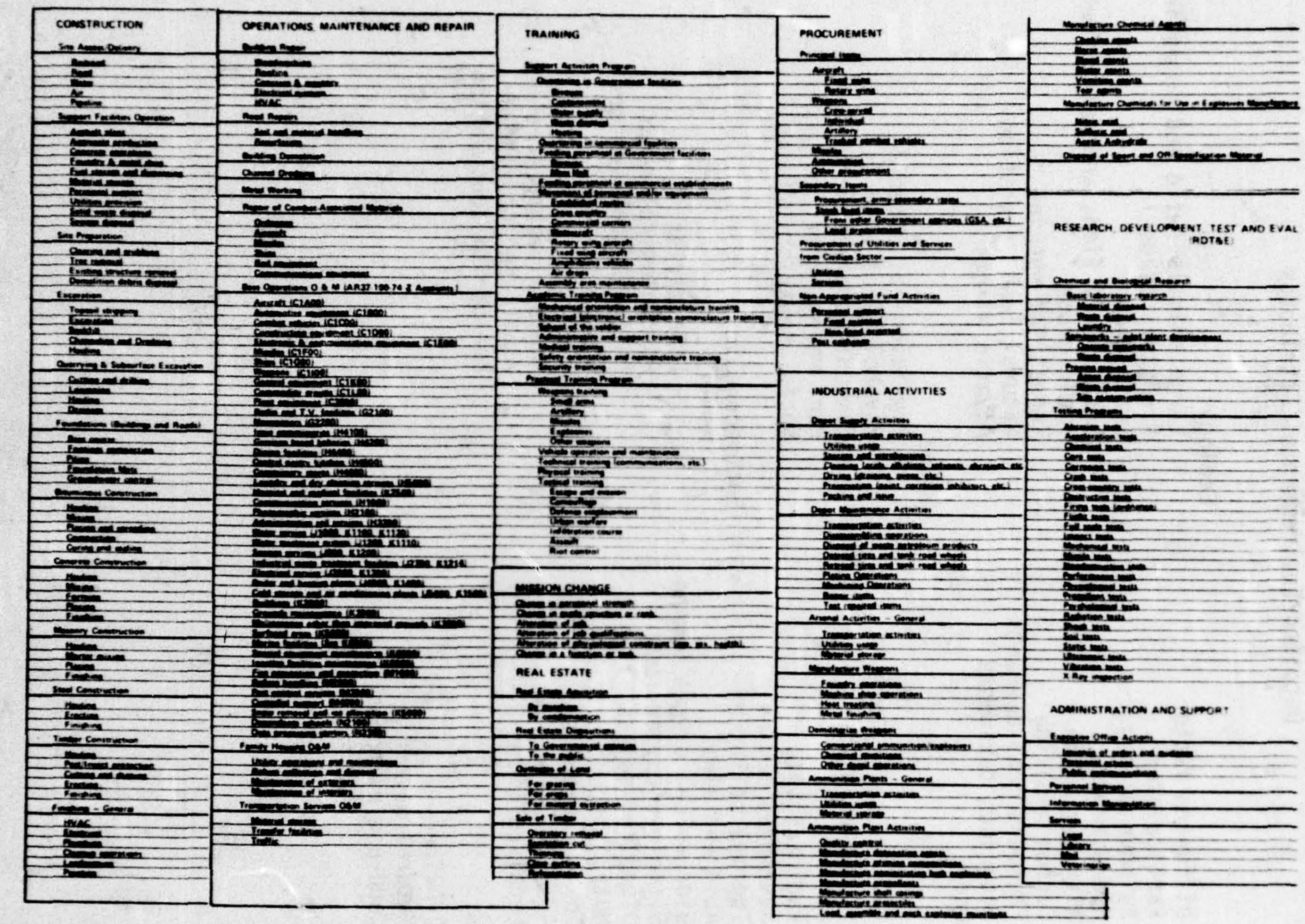


Figure 5. Detailed Army activities.

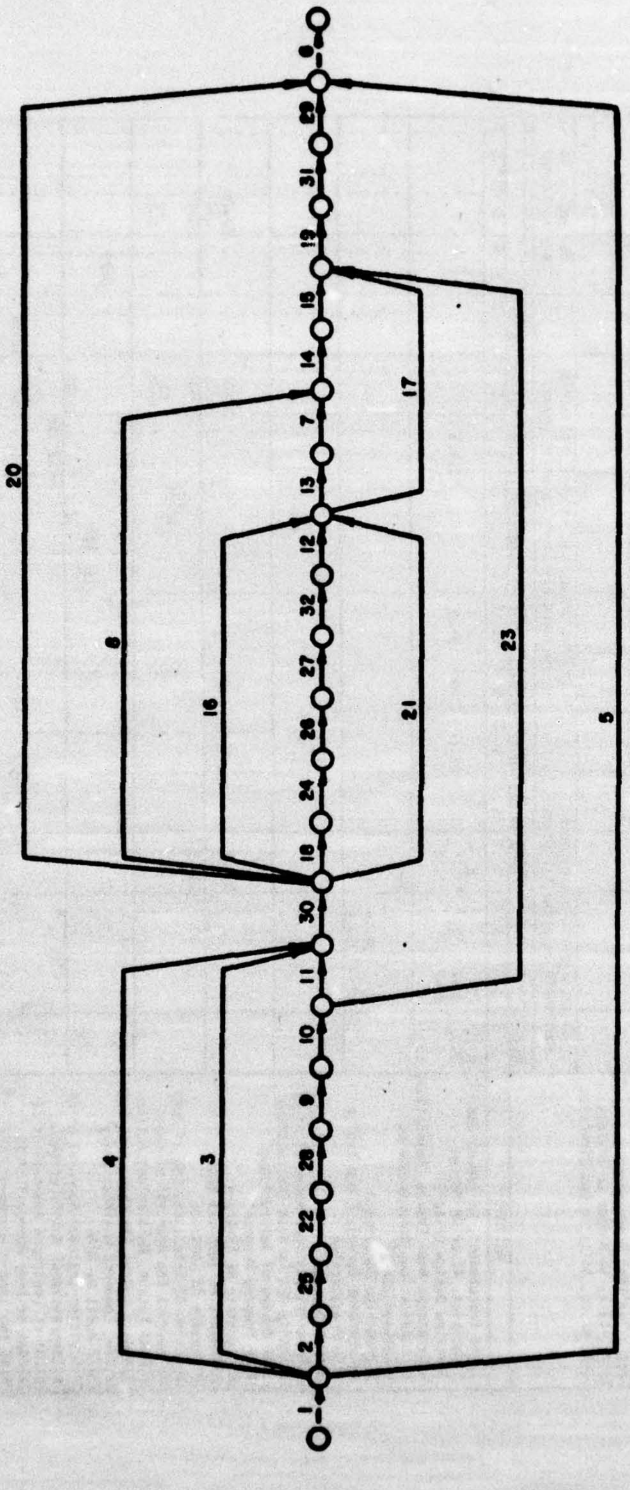


Figure 6. General architect-engineer procurement and District engineer predesign process network.

DECISION TABLE - ARCHITECT-ENGINEER PROCUREMENT AND DISTRICT ENGINEER PREDESIGN

CONDITIONS	RULES 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 DE, Normal Army & AF, Special Army	Y	-	-	-	-											
2 DE, Accelerated	-	Y	-	-	-											
3 AE, Accelerated	-	-	Y	-	-											
4 AE, Normal AF & Special Army	-	-	-	Y	-											
5 AE, Normal Army	-	-	-	-	Y											
6 AE > $ 2,500						Y										
7 AE > $ 10,000						-	Y	-	-	-	-	-	-			
8 AE > $ 10,000						-	-	Y	-	-	-	-	-			
9 AE > $ 100,000						-	-	-	Y	-	-	-	-			
10 AE > $ 100,000						-	-	-	-	Y	-	-	-			
11 AE > $ 150,000						-	-	-	-	-	Y	-	-			
12 AE > $ 500,000						-	-	-	-	-	-	Y	-			
13 AE > $1,000,000						-	-	-	-	-	-	-	Y			
14 AE, Two Step Procurement														Y		
15 AE, Delay in Notice to Proceed															Y	
16 AE or DE, Delay in Des Directive																Y
	In this group, use highest applicable rule and all lower					In this group, use highest applicable rule and all lower rules in group								Use any or as many as needed		

ACTIONS	Basic S	T	Add or Delete (/) or Reassign (→) Successor Actions (S) as Indicated: 2 S	T	3 S	T	4 S	T	5 S	T	6 S	T	7 S	T	8 S	T	9 S	T	10 S	T	11 S	T	12 S	T	13 S	T	14 S	T	15 S	T	16 S	T
1 (AE Procurement, DE Predes Start)	[illegible]	-	8	-			8	-																								
2 Decision, AE or DE Design	30		30-7		7-12 16		12-20 11				11-16		10-9		9-22						22-25											
3 Review Design Criteria	30		30-7				7-30																									
4 Determine Real Estate, Relocations	30																															
5 Coordination, Correspondence	30						30-6																									
6 (Design Start)		-		-		L		-		-		-		-		-		-		-		-		-		-		-		-		-
7 Predesign Conference			30		30-14																											
8 Determine Survey, Found Explor			30		30-14																											
9 AE Preselection													10																			
10 AE Selection											11						23															
11 District Engineer Approval of AE											3, or								12-24													
12 Notify AE, Furnish Instructions					13,17																											
13 AE Review of Instructions					7																											
14 AE Prepare Proposal					15																											
15 Negotiate AE Contract					30		30-19																30-31						30-29			
16 Prepare AE Instructions					13,17																		and						and			
17 Prepare AE Contract					30		30-19																30-31						30-29			
18 Review AE Selection, Chg if Need							12																									
19 District Eng Approval of Award							6												12 or 24				6 or 31						6 or 29			
20 Real Estate, Relocations Action							6																									
21 Update Budget Sketches, Cost Ests									13,17																							
22 Adv, Commerce Business Daily															9	14											9-28					
23 AE Audit by DCAA																	19	13														
24 Division Engineer Approval of AE																			12				12-26									
25 Congressional Notification																					22	14										
26 Chf of Engineers Approval of AE																							27									
27 Dept of Army Approval of AE																							12		12-32							
28 AE Two Step Procurement, RFP																											9					
29 AE Delay in Notice to Proceed																													6	?		
30 AE or DE, Delay in Des Directive	6	0					[illegible]	0	21	0																						?
31 Division Eng Approval of Award																							6						6 or 29			
32 Dept of Defense Approval of AE																									12							

Figure 7. Decision table - architect-engineer procurement and District engineer predesign.

Decision Table

The decision table is constructed in accordance with the general principles of what is usually called The Decision Logic Table Technique,[7] or the Decision Table Method.[8-10] The table provides rules by which a particular network can be generated in terms of the applicability of 16 hypothetical propositions (conditional statements or sentences) of the if--, then--, or antecedent-consequent types. That is, if a project contains a certain combination of conditions, the network will be formulated according to the rule (in this case, rules) which applies to that combination of conditions. The rule is a group of actions. The conditions are related to input, and actions are related to output (the network). Certain variations in the general decision logic table technique have been used to apply the technique to this problem. In Figure 7, the Conditions-Rules array has test elements only in the main diagonal. Consequently, this array can be replaced by using the conditions as column headings for the Actions-Rules array.

Conditions

There are 16 conditions (see Figure 7). Each corresponds to a factor that significantly affects the activities' existence, sequence, and scaled time.

Each of the first five conditions is determined by the pace of the procurement action. The next eight conditions are determined by the estimated cost of the A/E design contract. Each of the last three conditions is specified by a single input variable, which specifies the continuity of the design process. Thus, there are five input variables. There are two $10,000 cost conditions, since there are two totally unrelated actions specified for this dollar limitation. For the same reason, there are two $100,000 cost conditions.

Actions

Actions arise from existing conditions. The two dummy actions (start and end) arise from the use of activity-on-node notation in the rules. An activity network, as for CPM (The Critical Path Method), may have numbered activities (activity-on-node) or numbered events (activity-on-arrow). The activity-on-node notation allows use of the action numbers; an action is succeeded by one or more actions. Otherwise, the

---

[7] *The Decision Logic Table Technique,* AFP 5-1-1 (Department of the Air Force, September 1965).

[8] S. L. Pollack, et al., *Decision Tables: Theory and Practice* (Wiley-Interscience, 1971).

[9] H. McDaniel, editor, *Applications of Decision Tables--A Reader* (Brandon/Systems Press, Inc., 1970).

[10] H. McDaniel, *Decision Table Software--A Handbook* (Brandon/Systems Press, Inc., 1970).

use of activity-on-arrow would require the confusing superpositions of another 31 event numbers over the 30 activity numbers; and each reassignment of activity sequence would involve renumbering an activity predecessor event and a successor event. With activity-on-node notation, only successor activities need to be renumbered when an activity sequence changes. Using the action numbers as either the predecessor event numbers or the successor event numbers is not a feasible approach.

The networks shown in Figures 8 to 13 were used as a guide. These networks, provided by the Savannah District, have remained consistently implementable. The decision table satisfies the requirements of these six networks. The six can be used in five possible combinations (the first five conditions). It will be noted, however, that the Savannah District Office networks fix the conditional actions 9, 10, 11, 19, and 24; float actions 29 and 30; lump actions 19 and 31; and omit actions 22, 23, 26, 27, 28, and 32.

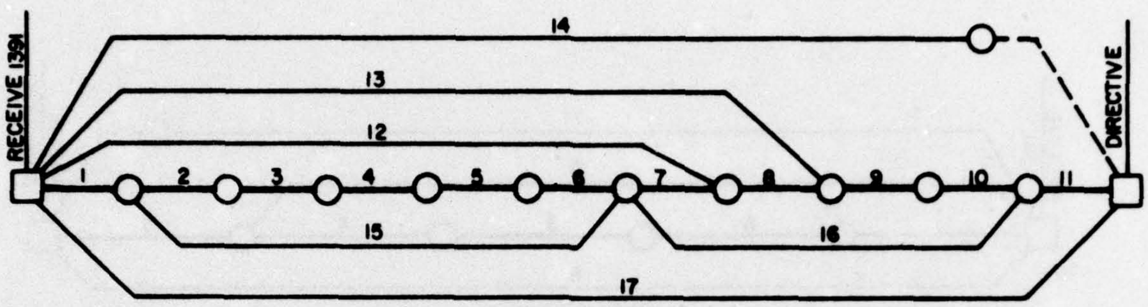
Rules

If a condition (antecedent) is affirmed (Y = yes), one or more rules are invoked; in turn, each rule invokes one or more actions (consequents). Conditions may exist in only two states--yes or no. The theoretical third state (immaterial or indifferent) does not apply to these networks.

Each rule requires a test of a condition for applicability and for actions to be taken (the S, or successor activity column, and the T, or activity time or duration column) if the condition applies. Each action requires that: (a) one or more successor activities be added (assigned), or deleted (removed), or changed (replaced, reassigned, modified); and/or (b) activity times be correspondingly adjusted.

There are 16 conditions and only 16 rules columns in the decision table of Figure 7. This implies that it is not physically possible to have all possible combinations of the rules. For n m-state conditions, there are at most m^n possible condition combinations. Thus, if there are 16 two-state conditions, there are a maximum of 2^{16} = 65,536 possible combinations. Fortunately, having more than five conditions is impractical when all possible combinations are feasible. The 16 conditions of the decision table have the following combinations: (1 or 2) and (16 or not 16); (3 or 4 or 5) and [not 6 or 6 or (6 and 7) or (6 and 7 and 8) or . . . . or (6 and 7 and . . . and 13)] and (14 or not 14) and (15 or not 15) and (16 or not 16). Numerically, this adds up to (2 x 2) + (3 x 9 x 2 x 2) = 4 + 216 = 220 feasible combinations or networks.

Procedures for using the rules are given in the column headings of Part II of the decision table. Here, a network is being built by adding actions to satisfy applicable conditions. This is simpler than using an all-inclusive network and subtracting actions corresponding to inapplicable conditions. Certainly, it is simpler during table design because



Sub-Net No. 10

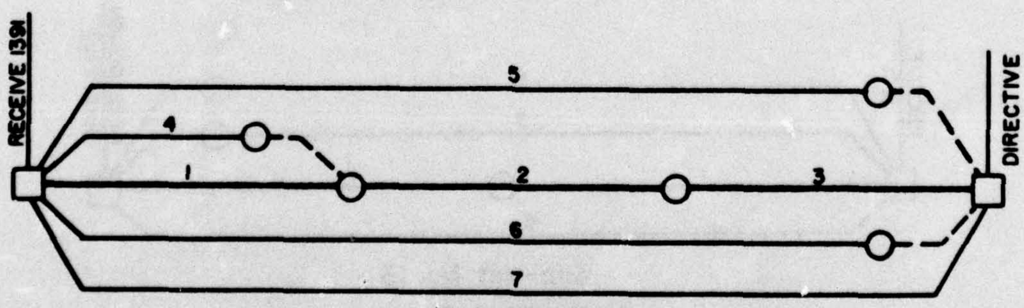
Figure 8. A/E procurement network, accelerated.

Sub-Net No. 10

Activity	Description
1	DECISION, AE OR DE DESIGN
2	AE PRE-SELECTION ACTION
3	AE SELECTION ACTION
4	DE APPROVAL OF AE
5	SAD APPROVAL OF AE
6	NOTIFY AE
7	AE REVIEW INSTRUCTIONS
8	PRE-DESIGN CONFERENCE
9	AE PREPARE PROPOSAL
10	NEGOTIATE AE CONTRACT
11	FLOAT TIME
12	REVIEW CRITERIA
13	DETERMINE EXTENT OF SURVEY AND FOUNDATION EXPLORATION
14	DETERMINE EXTENT OF REAL ESTATE AND RELOCATIONS, IF ANY
15	PREPARE AE INSTRUCTIONS
16	PREPARE AE CONTRACT
17	COORDINATE, ANSWER CORRESPONDENCE

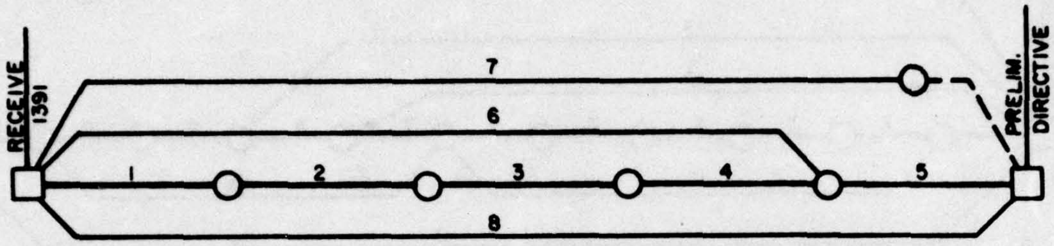
Sub-Net No. 11

Activity	Description
1	DECISION, AE OR DE DESIGN
2	PRE-DESIGN CONFERENCE
3	FLOAT
4	REVIEW CRITERIA
5	DETERMINE EXTENT OF REAL ESTATE OR RELOCATIONS, IF ANY
6	DETERMINE EXTENT OF SURVEY AND FOUNDATION EXPLORATION
7	COORDINATE, ANSWER CORRESPONDENCE, ETC.



Sub-Net No. 11

Figure 9. DE predesign network, accelerated.



Sub-Net No. 12

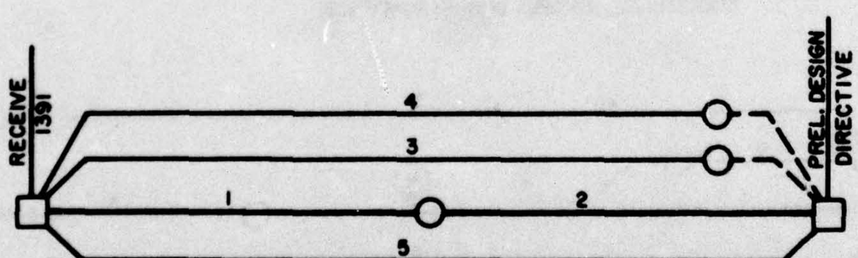
Figure 10. A/E procurement network, normal speed, predirective.

Sub-Net No. 12

Activity	Description
1	DECISION, AE OR DE DESIGN
2	AE PRE-SELECTION ACTION
3	AE SELECTION ACTION
4	DE APPROVAL OF AE
5	FLOAT TIME
6	REVIEW CRITERIA
7	DETERMINE EXTENT OF REAL ESTATE AND RELOCATIONS, IF ANY
8	COORDINATE, ANSWER CORRESPONDENCE

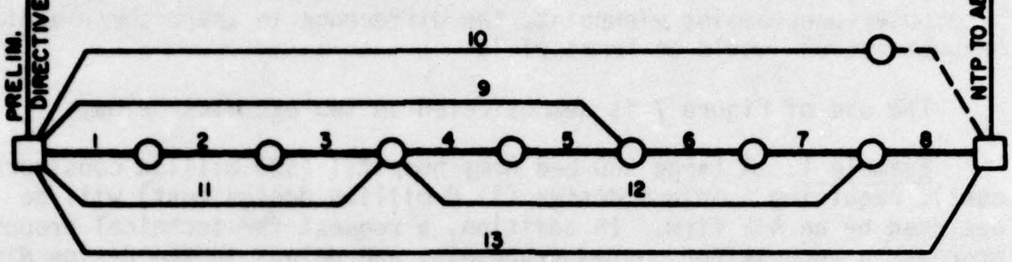
Sub-Net No. 13

Activity	Description
1	DECISION, AE OR DE DESIGN
2	FLOAT TIME
3	REVIEW CRITERIA
4	DETERMINE EXTENT OF REAL ESTATE AND RELOCATIONS
5	COORDINATE, ANSWER CORRESPONDENCE



Sub-Net No. 13

Figure 11. DE predesign network, normal speed/



Sub-Net No. 20

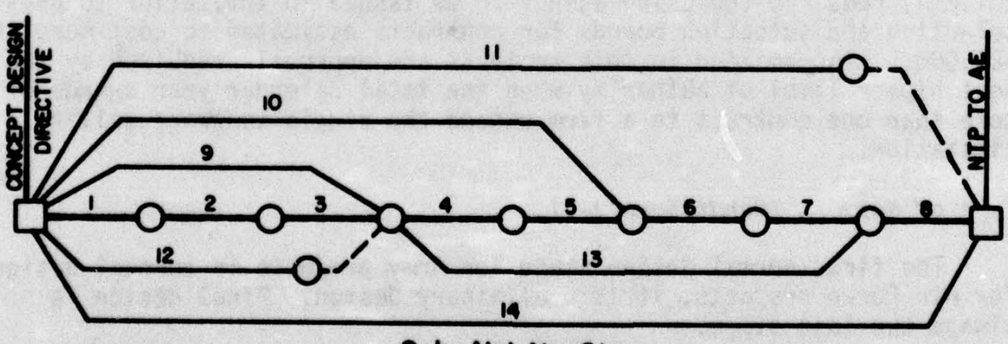
Figure 12. A/E procurement network, normal speed, post-directive, Air Force and specialized Army projects.

Sub-Net No. 20

Activity	Description
1	REVIEW AE SELECTION, CHANGE IF REQUIRED
2	SAD APPROVAL OF AE
3	NOTIFY AE
4	AE REVIEW INSTRUCTIONS
5	PRE-DESIGN CONFERENCE
6	AE PREPARE PROPOSAL
7	NEGOTIATE AE CONTRACT
8	AWARD AE CONTRACT
9	DETERMINE EXTENT OF SURVEY AND FOUNDATION EXPLORATION
10	REAL ESTATE AND RELOCATIONS ACTION, IF ANY
11	PREPARE AE INSTRUCTIONS
12	PREPARE AE CONTRACT
13	COORDINATE, ANSWER CORRESPONDENCE

Sub-Net No. 21

Activity	Description
1	REVIEW AE SELECTION, CHANGE IF REQUIRED
2	SAD APPROVAL
3	NOTIFY AE
4	AE REVIEW INSTRUCTIONS
5	PRE-DESIGN CONFERENCE
6	AE PREPARE PROPOSAL
7	NEGOTIATE AE CONTRACT
8	AWARD AE CONTRACT
9	PREPARE AE INSTRUCTIONS
10	DETERMINE EXTENT OF SURVEY
11	REAL ESTATE AND RELOCATIONS ACTIONS, IF ANY
12	UP-DATE BUDGET SKETCHES AND ESTIMATES
13	PREPARE AE CONTRACT
14	COORDINATE, ANSWER CORRESPONDENCE



Sub-Net No. 21

Figure 13. A/E procurement network, normal speed, post-directive, normal Army projects.

visualizing the all-inclusive network is difficult to impossible. From a computer-programming viewpoint, the difference in approaches--addition or subtraction--would be immaterial.

The use of Figure 7 is demonstrated in two examples below.

Example 1. A large 300-bed Army hospital ($30 million construction cost), requiring a unique design ($1.8 million design cost) will be designed by an A/E firm. In addition, a request for technical proposals precedes a request for costed proposals, and delays in the design directive and the design contractor's notice to proceed are anticipated. The design is to follow the two normal stages--concept and final. In this case, all 16 rules apply. The network appears as shown in Figure 6.

Example 2. If a design is of the normal Air Force type, is designed by an A/E, costs $125,000, and uses two-step procurement, then Conditions 4, 6, 7, 8, 9, 10, and 14 apply. Condition 4 automatically invokes rules 1, 2, 3, and 4 to build the network to satisfy condition 4. Conditions 6, 7, 8, 9, 10, and 14 invoke rules 6, 7, 8, 9, 10, and 14, adding onto the network. Alternatively, Condition 10 can be understood to invoke rules 6, 7, 8, 9, and 10.

Appendix A provides the entire 220 networks, which were machine-generated from the decision logic table.

Only salient points about major factors influencing the process were discussed above. Certainly, Corps direct office predesign activities represent a host of actions by procurement personnel in collaboration with engineers. Figures 14 and 15, the ENG Forms 3726 and 3726-1 (the 77-item Official Contract Record Checklist--Pre-award and Award) provide details about the A/E contract process. No allowance has been made in this analysis for competitive award of design contracts rather than contractor selection. Competitive awards are permissible, but contrary to practice and engineering ethics. No allowance has been made for recycling the process if there is a system breakdown at some stage; this rarely occurs. Engineer Regulation (ER) 1180-1-1, Para. 75-201.2(a) requires the using agency to be issued an invitation to preselection and selection boards for contracts estimated to cost more than $25,000. Also omitted in this analysis are approvals required by the next higher level of authority when the total calendar year awards of more than one contract to a firm exceed the single contract dollar limitation.

Type of Network (Conditions 1-5)

The first normal design state for Army projects is concept design; for Air Force projects, it is preliminary design. Final design is always the last stage.

There are five distinct types of networks (see Figure 7) which depend on: (a) choice of whether the design should be done by District forces or by contract; (b) choice of predesign pace--accelerated or

OFFICIAL CONTRACT RECORD CHECKLIST - PRE-AWARD

CONTRACT NUMBER	DATE	☐ ADVERTISED ☐ NEGOTIATED
CONTRACTOR		TYPE OF CONTRACT: ☐ CONSTRUCTION ☐ ARCHITECT ENGINEER ☐ SUPPLY

SECTION A - PRE-AWARD

TAB	ITEM	CHECK COLUMN IF APPLICABLE	CHECK COLUMN IF IN FILE OR WRITE IN LOCATION
	1. Procurement Directive or Purchase Request.		
	2. Determination and Findings justifying negotiation; Request for authority to negotiate; approval to negotiate.		
	3. Miscellaneous commitment document or other evidence of availability of funds.		
	3a. Prequalification - justification and approval.		
	4. Small Business or Labor Surplus Area Set-Aside determinations. Narrative statement indicating reasons for non-Set-Aside.		
	5. Synopsis of proposed procurement.		
	5a. Sole source procurement - justification and approval.		
	6. Advance notice and record of distribution.		
	6a. Proprietary Specification - justification, approval and report to OCE.		
	7. Justification for type of contract used, if required.		
	8. Government Estimate, signed, dated, and approved. Backup material on price and cost data or reference to location.		
	9. Bidders mailing list; justification for limited list; evidence that firms were checked against debarred bidders lists; list of firms or persons whose requests for copies of the solicitation were denied, together with reasons for denial.		
	10. Clearance for bid opening dates, when required.		
	11. Security Requirement Check List (DD Form 254) and evidence of contractor clearance.		
	12. Minutes of pre-bid and pre-design conferences.		

ENG FORM 3726 SEP 67 EDITION OF 1 APR 66, IS OBSOLETE. PAGE 1

Figure 14. ENG FORM 3726: Official Contract Record Checklist - Pre-award.

SECTION A – PRE-AWARD *(Continued)*			
TAB	ITEM	CHECK COLUMN IF APPLICABLE	CHECK COLUMN IF IN FILE OR WRITE IN LOCATION
	13. A copy of Invitation for Bids or Request for Proposals, including specifications and drawings or reference to location; amendments; evidence of review by counsel.		
	14. One copy of each signed solicited or unsolicited bid, proposal or quotation received, including record of determination concerning late bids, proposals or quotations. (While unsuccessful bids, proposals or quotations are a part of the official file, they may be maintained separately, cross-referenced to the contract file, and disposed of as provided in S2-501(i), ASPR); successful bid with bid bond.		
	15. Abstract of Bids or Summary of Proposals.		
	16. Bidders Statement of Contingent Fees including, when pertinent, STD Form 119 (Contractors Statement of Contingent or other Fees).		
	17. Justification for rate of liquidated damages used.		
	18. A copy of each pre-award survey performed or reference to previous surveys accepted.		
	19. Notice to unsuccessful bidders.		
	20. Findings for bid rejection.		
	21. Notice to bidders of rejection of all bids, stating the reasons for such action.		
	22. Protest of Government Estimate.		
	23. Notification to late bidders.		
	24. Mistake in bid with requests, determination, submissions to OCE and approvals or disapprovals.		
	25. Statement with respect to receipt and disposals of late bids.		
	26. Determination with respect to withdrawals of bids.		
	27. Verification of bid.		
	28. Protest of award.		
	29. Unbalanced bids.		
	30. Report of identical bids.		
	31. Determination of contractor responsibility.		

PAGE 2

Figure 14 (cont'd).

SECTION A - PRE-AWARD *(Continued)*			
TAB	ITEM	CHECK COLUMN IF APPLICABLE	CHECK COLUMN IF IN FILE OR WRITE IN LOCATION
	32. Small Business Administration Certificate of Competency.		
	33. Audit reports or reasons for waiver.		
	34. A complete record of negotiations, including but not limited to, participants, dates of meetings or phone calls; Government-furnished materials or facilities provided. Subcontracting, terms and conditions agreed to; deviations, if any, from prescribed contract clauses; technical recommendations; and justification for final price. ENG Form 2180 and 2180a.		
	35. Documentation of any changes in Government estimate made during or after negotiations.		
	36. Cost and pricing data submitted or used, including Certificates of Current Cost or Pricing Data.		
	37. Price analysis.		
	38. Packaging and transportation data or analysis.		
	39. Exceptions or exemptions from the Buy American Act or Appropriation Act restrictions.		
	40. Required approvals of award.		
	41. Selection of successful contractor and reasons for selection.		
	42. Verification of requirements.		
	43. Copy of Statement and Certificate of Award (STD Form 1036).		
	44. Other: a.		
	b.		
	c		
	d.		
	e.		

PAGE 3

Figure 14 (cont'd).

OFFICIAL CONTRACT RECORD CHECKLIST - CONTRACT		CONTRACT NO.	
SECTION B - CONTRACT			
TAB	ITEM	CHECK COLUMN IF APPLICABLE	CHECK COLUMN IF IN FILE OR WRITE IN LOCATION
	1. Notice of Award.		
	2. Memo of Report to OCE and Congressmen of release of information on Army Contract Awards.		
	3. Synopsis of award.		
	4. Individual Procurement Action Report (DD Form 350).		
	5. Signed Contract (with evidence of review for legal sufficiency) with letter transmitting contract to Contractor. Include Corporate Certificate, if a Corporation.		
	6. Performance and Payment Bonds.		
	7. Post award conference record (DD Form 1484).		
	8. Non-discrimination material.		
	9. Insurance policies or certificates; Commitment of Insurance Company RE: Termination Notice.		
	10. Notice to proceed.		
	11. Pre-construction conference or letters as to enforcement and administration of contract provisions.		
	12. Contractors safety program with minutes of pre-construction Safety Conference.		
	13. Designation of authorized Representative of the Contracting Officer, with evidence of copy being furnished the contractor.		
	14. Designation of property administrator.		
	15. Letter RE: Labor Relations. Records of compliance with labor policies, equal employment opportunity policies.		
	16. Statement that the wage determination is posted at the project site.		
	17. Labor complaints.		
	18. Payrolls and statements or reference to location.		
	19. Payroll investigation or reference to location of records.		
	20. List of subcontractors.		

ENG FORM 3726-1 SEP 67 EDITION OF 1 APR 66, IS OBSOLETE. PAGE 1

Figure 15. ENG FORM 3726-1: Official Contract Record Checklist - Contract.

SECTION B - CONTRACT *(Continued)*			
TAB	ITEM	CHECK COLUMN IF APPLICABLE	CHECK COLUMN IF IN FILE OR WRITE IN LOCATION
	21. Progress schedules or reference to location.		
	22. Request and approval for overtime.		
	23. Approvals or disapprovals of waivers or deviations.		
	24. Royalty, invention, and copyright reports or reference to location.		
	25. Documents or data for renegotiation.		
	26. Documents denoting completion of the contract, including contract completion statement (DD Form 1594) when applicable.		
	26a. DD Forms 1596 and 1413 as applicable.		
	27. Procurement action completion report, as required.		
	28. Miscellaneous correspondence pertaining to administration of contract, filed in chronological order with applicable portion of file.		
	29. Letter of final acceptance.		
	30. Property documents or reference to location.		
	31. Fiscal documents or reference to location.		
	32. Shop drawings and as-Built Drawings or reference to their location.		
	33. Documents for termination and claims or reference to location.		
	34. Completed DD Forms 1593 and 1597 as applicable.		
	35. Other: a.		
	b.		
	c.		
	d.		

PAGE 2

Figure 15 (cont'd).

usual; (c) using agency; and (d) a third design stage for specialized, complex projects. These four considerations, related to Conditions 1-5, are shown in Table 7.

Table 7

Network Type (Condition) - Classified by Designer, Pace, User, Stages

Predesign Process Pace, Using Agency, Number of Design Stages	Design by District	Design by Arch-Engr
Accelerated, Army and Air Force 2-Stage	2 (See Fig. 9)	3 (See Fig. 8)
Normal Pace, Air Force, 2-Stage	1 (See Fig. 11)	4 (See Figs. 10, 12)
Normal Pace, Army, 3-Stage (Specialized)	1 (See Fig. 11)	4 (See Figs. 10, 12)
Normal Pace, Army, 2-Stage	1 (See Fig. 11)	5 (See Figs. 10, 13)

Architect-Engineer Selection (Condition 6)
(Alternative--In-House)

The Armed Services Procurement Regulation (ASPR), Para. 18-402.2(f), requires selection of an A/E firm by a selection board for contracts estimated to cost more than $2500. Engineer Regulation (ER) 1180-1-1, Para. 75-201.2(a), requires that the preselection board be composed primarily of senior staff architects or engineers from the Engineering and Construction Divisions (District or Division Office, whichever is the construction activity) or military personnel having comprehensive experience in construction.

District Engineer Approval of Selection
(Condition 6)

ASPR Para. 18-402.2.2(i) requires that A/E selections be approved by the head of a construction activity or his designee. In practice, a designee, such as a supply and procurement officer, may approve selections up to some dollar limitation.

Architect-Engineer Preselection (Condition 7)
(Alternative 2--Out-of-House)

ASPR Para. 18-402.2(f) requires preselection of A/E firms when the estimated contract cost is greater than $10,000. ER 1180-1-1 requires the same type of composition for the preselection board as for the selection board, with the limitation that no one may serve on both boards.

Advertisement, Commerce Business Daily
(Condition 8)

Defense Procurement Circular #109, Item III, revises ASPR Para. 1-1003.4(b)(2) to require public notification in the *Commerce Business*

Daily of procurement of A/E services where the total fee is expected to exceed $10,000. This applies in the United States, its possessions, or Puerto Rico. The advertisement specifies the allowable response date, which is generally 10 days or more. Advertisement must precede selection and preselection (if any).

Audit by Defense Contract Audit Agency (DCAA) (Condition 9)

ASPR Para. 3-801.5(b)(1) requires that prior to negotiation of an A/E contract or a modification in excess of $100,000 (where the price is based on cost or pricing data submitted by the contractor), the contracting officer or his authorized representative shall request a field-pricing support report (including audit review by the contract audit agency). This can be waived if information already available to the contracting officer is adequate to determine the reasonableness of the proposed cost or price. Generally, DCAA audits contracts estimated to exceed $100,000 and does not encourage requests for audits for lesser contracts because of the continuously heavy DCAA case load. A wide range of services is available from DCAA, including interpretation of audit findings and legal counsel. Audits for contracts estimated to cost less than $100,000 may be requested from other sources, such as the Defense Contract Administrative Services Region. The audit may or may not be in the procurement activity network critical path. If a narrow, legalistic approach is taken, it is not logically possible to request an audit prior to receiving a firm, detailed contractor price proposal, and the audit must be completed prior to negotiation. DCAA prefers this approach, since its energies are then not expended wastefully in auditing several potential contractors, with incompleted data. The audit sequence recommended herein is subsequent to A/E selection and prior to completion of negotiations.

Division Engineer Approval of Selection (Condition 10)

ASPR Para. 18-402.3(i) requires selection approval of the next higher organizational level (Division Engineer) of the construction activity, when the estimated cost of an A/E services contract to be awarded by a field activity exceeds $100,000.

Congressional Notification (Condition 11)

Defense Circular #109, Item III, revises ASPR Para. 1-1003.4(b) (2) to require that no public announcement be made until 2 weeks after Congress has been notified about an A/E services procurement that has an estimated total fee of $150,000. Congress should be notified in accordance with Section 612 of Public Law 89-568. The expression "public announcement" corresponds to advertisement in the *Commerce Business Daily* in the United States, its possessions, and Puerto Rico.

Division Engineer Approval of Award (Condition 12)

Engineer Circular (EC) 1180-1-140 authorizes the Division Engineer to approve the award of military A/E contracts for nonpersonal services without monetary limitation. The EC places a $500,000 limitation on District Engineers. The current (1 December 1969) more restrictive ER 1180-1-1, Para. 1-405.5(a) will be amended to reflect the authority stated in EC 1180-1-140.

Chief of Engineers Approval of Selection (Condition 12)

ASPR Para. 18-402.3(iv) requires selection approval by the Secretary of the Army or his designee when the estimated cost of an A/E services contract exceeds $500,000. The designee is the Assistant Secretary of the Army (Installations and Logistics).

Department of Defense Approval of Selection (Condition 13)

ASPR Para. 18-402.3(v) requires selection approval by the Assistant Secretary of Defense (Installations and Logistics) or his designee when the estimated cost of an A/E services contract exceeds $1 million. The designee is the Deputy Assistant Secretary of Defense (Installations and Housing).

Architect-Engineer, Two-Step Procurement (Condition 14)

Public announcement in the *Commerce Business Daily* (Condition 8) is presupposed; this is the invitation for prospective contractors to provide statements of qualification and intent. After public announcement, qualified firms are invited to give a more technical proposal, which would outline fairly precisely such things as the scope, types of materials, and extent of site work. The time consumed by a District Office to evaluate proposals, in addition to that normally required in the preselection process, should also be considered. Any separate request for priced proposals can then be considered as added time between announcement and preselection.

Architect-Engineer, Delay in Notice to Proceed (Condition 15)

A delay in notice to proceed can occur, but is difficult to anticipate. An allowance can be made for probable delay if data are available. A number of situations could cause delay, among which are withdrawal of funds, protest of award, and protest of the government estimate.

Delay in Design Directive (Condition 16)

A delay in design directive will stop the procurement process. The procurement cycle was begun in anticipation of receiving a design directive.

A delay is difficult to anticipate but an allowance can be made for probable delay if data are available. The last action which can be taken before receiving a design directive is District Engineer approval of contractor selection (conditioned on directive receipt).

Activity Times

Activity times not set by regulation will be computed from estimates by Corps of Engineers offices having military design responsibility. These offices are:

HND U.S. Army Engineer Division, Huntsville

MRO U.S. Army Engineer District, Omaha

NAB U.S. Army Engineer District, Baltimore

NAN U.S. Army Engineer District, New York

SAM U.S. Army Engineer District, Mobile

SAS U.S. Army Engineer District, Savannah

SPK U.S. Army Engineer District, Sacramento

SWF U.S. Army Engineer District, Fort Worth

Design Process (Preconstruction)

Modeling the design process presents a number of problems. The following discussion outlines these problems, concluding with a recommended modeling scheme.

Complexity

An activity network for original design is influenced by such variables as:

a. Facility class and construction category, or project type

b. Scope, or project size

c. Number of repetitive units in the project

d. Design type, such as original, standard, or site adaption

e. Design pace--normal or accelerated

f. District office management policies

g. Scheduling problems: job peaking and manpower restrictions

h. Man and machine data-handling limitations--past, present, and future.

Other factors (such as skill requirements, number of design phases, and design reviews) are dependent on these variables and will be considered when the corresponding influencing variable is examined.

Facility Class and Construction Category

AR 415-28 lists approximately 800 distinct facility types by class, category group, basic category, and specific item. AFM 300-4 provides a similar listing for 800 facility types. However, ER 415-345-12 suggests that the specific item effect can be ignored and that there are approximately 32 relatively distinct facility types in terms of a construction time-scope relation. A similar reduction could probably be made for design purposes--from 800 to approximately 30. The kind and relative quantity of skills required (architectural, civil, electrical, mechanical, structural, estimating, specifications, drafting, etc.) varies with respect to facility type. Certainly, mechanical and electrical engineers tend to spend a larger fraction of design funds (and time) for a utility design, as contrasted with a building design. On the other hand, airfield pacing design can be characterized by an absence of architectural and mechanical labor. There can be other, less significant differences between facility classes, as with the design-cost design-time relations.

Scope

The scope, or the number of measurement units (square feet, square yards, linear feet), has some effect on the type, length, and cost of activities, the number of design phases, and the number of agency reviews. The type of activities is most strongly related to facility class and construction category. Activity time can be related to activity cost. Wherever possible, network representations should be time-independent in the sense that relative, rather than dollar costs should be used to avoid time dating and scaling of cost data. Scope will be used primarily as a measure of the required amount of time, design phases, and agency reviews. Scope can also be used to measure the effect of repetitive design on a given facility or project.

Number of Repetitive Units

When a facility (or project, which is a collection of facilities) has many similar units, such as a large power plant, enlisted men's barracks complex, or family housing complex, designing of the first similar unit requires the most time. An explicit activity network representation of this distinction is only marginally desirable. The effect can be handled implicitly in activities which lump all similar units together and consider time and cost relations as a function of scope.

Design Type

Design time and cost are greatest for an original design; using a standard design or the site adaptation of a previous design should reduce the required design effort. A variance in design time and costs

for any group of projects similar in facility class, construction category, and scope should be traceable to differences in design type. It would be expected that standard designs or an adaptation would be weighted more heavily for survey, foundations, and materials than for other skills.

Design Pace

When a normal crew size cannot accomplish sequential design activities, more men or concurrency of activities is required to accelerate the work. Acceleration of in-house work usually requires concurrency, since manpower is limited to a force sufficient to accomplish only 15 to 50 percent of the total workload. An A/E firm might employ one or both options.

District Office Management Policies

A Corps District office can limit work to only some types of facility design. Such a policy, applied consistently, would not affect networks on a year-to-year basis. A District office, whose design funding is limited, may not find a willing A/E. This too should not *explicitly* affect a network, since portions of the design may have to be accomplished privately. The existence of such situations will cause the validity of records on one or more projects which must support one which is underfunded to be questionable. While maximum design cost target levels are applied agency-wide, there is evidence that some Districts do not design to the maximum allowed cost. Though network complexity is unaffected by such a decision, design time can be. Probably the greatest effect on complexity arises from the way a District office views the design process. Generally, a District office is organized (structured) in a functional skill pattern, in accordance with ER 10-1-3. This ER is fairly specific about organization down to the branch level. However, branch structure is controllable by Division Engineers (with a few exceptions) and delegable to District Engineers. When District organization charts are compared, many structural similarities and dissimilarities become apparent. Dissimilarities would be expected to be greatest at the section and unit levels. Generally, the output of one District and its contractors is similar to that of another; however, the views of the process are different, as can be seen by comparing District design networks. The individual District concept of the design process is bound to affect management of in-house and out-of-house design.

Scheduling Problems

Manpower scheduling problems were mentioned previously in connection with the discussion of design pace. Awarding contracts to A/E firms is not a universal solution to the problem of peaking of design starts; at best, it only provides more relief. In-house engineering resources are required for: (1) A/E procurement activities; (2) predesign and design activities which cannot be assigned to private firms; and (3) contract management. These peak scheduling problems are

difficult to represent explicitly in network form. The most obvious effect is disruption of some in-house project design and consequent lengthening of design time. Due to ASPR A/E selection process approval requirements, there is encouragement to spread work among qualified firms, both regionally and nationwide. Also, it is difficult to force work on an unwilling and/or overburdened firm. Therefore, contracted work should be relatively free of peaking effects.

Data Handling Limitations

Discussion of network complexity should be limited to that which is manageable by engineers and computers. Since estimates of future work are based on past performance, discussion of factors for which there are no present or foreseeable data is pointless. For example, there are few records which could be retrieved easily that would relate design time to design type, although this defect can and should be readily eliminated in the future. The ability of machines and humans to create and update networks is limited. Where a District must manage up to 700 project networks, some average limit must be placed on network size to stay within current and future computer hardware and software capabilities. For large civil works jobs, 120 activities have been found adequate to cover design through construction. Facility design cost, divided by the amount of the lowest cost-design activity which may reasonably be monitored, yields the upper limit of facility design network activities. The average facility design cost is approximately 70,000 FY 75 dollars. If it is desirable to monitor design activities at the $2000 level (3 man-weeks), an average network size of 35 activities is indicated. Manual creation and updating of networks, based on very limited manual input, encounter two problems which limit network size. One problem is that predictions must be made from limited historical information. Machine creation of networks depends on data recorded for completed projects. Machine updating, which depends on using fiscal data to represent physical progress (as individual cost-labor cards), limits activity networks to financial computer-program capabilities. The other problem is that programming must be significantly increased to maintain network quality goals for any increase in network size. Thus, network complexity is influenced by at least five major data-handling limitations: (1) the absolute tolerable manual labor for network creation, updating, and study; (2) the minimum size of unit of work which is controllable and worthwhile to monitor; (3) the contents of any historical data bases used, such as data on completed projects and data on current projects, some of which may come from interfaced data systems (e.g., finance and accounting); (4) the intelligence built into computer programs--both those which create and update networks, and those of interfaced data systems; and (5) computer hardware capacities.

Summary

A practical design network should provide for the effects of:

a. Facility class and construction category on design discipline times and costs. Perhaps 10 to 30 weighting schemes may suffice.

b. Scope (given facility class and construction category) on absolute time and cost estimates, number of agency reviews, and number of repetitive units.

c. Design type on skill-related time and cost weights and absolute time and cost estimates.

d. Design pace on activities sequence, as determined by comparing estimated normal time required and time allotted.

e. District office management policies on activity structure and weights of skill-related time and costs.

f. Scheduling problems on activities sequence. The network should be easily manipulated by any computer programs which attempt to level manpower requirements.

g. Man and machine data-handling limitations on number of activities per project. Perhaps 30 or 40 activities is a good target size for the near future.

Project data requirements fall into two categories--historical project data and current project data (Table 8). It makes no difference in data requirements whether the networks are produced by man, machine, or a combination of the two. Quantified activities for planned projects can be produced only from valid, organized data for previously completed projects. These data can be manipulated and summarized only to the extent that they are represented in a form common to all projects. Similarly, current project data must have commonality, of themselves and with historical data with which they will be merged.

Figure 16 is the generalized design network adopted for this study; Figure 17 is the normal designated design phases for Fort Worth. Figure 18 illustrates the specific design work and normal order of precedence for each phase at Fort Worth.

Advertisement and Award Process

Figure 19 illustrates a general advertisement and award process network. The process is straightforward, since it is primarily administrative and has a minimal dependence on design and construction work features. Pre-award survey activities, listed on the ENG Form 2459 (Figure 20) are not networked. Procurement activities indicated in Figures 6 and 7, which must also be performed as required for the individual project, are not networked.

Figure 19 shows two amendment cutoff periods--one for specifications and one for drawings. Both periods are shown as identical, since each cutoff period has a different predecessor activity which is an amendment period. Both amendment periods are identical (the same start and end date). All activities occur for ordinary projects.

Table 8

Network Data Requirements - Both Completed and Current Projects

Project Identifiers
- Facility class and construction category
- Project description (title)
- Scope (number of units)
- Unit of measure (of scope)
- Design type (original, standard, site adaption. . .)
- Fiscal year (design)
- Control cost (dollars)
- Contract number (if any)
- Reporting organization (designing District)
- Type funds (agency program)
- Authorization year (construction begins)
- Project number
- Station (location)

Activities
- Sequence (predecessor, successor events)
- Duration (days)
- Cost (dollars)
- Organizational element (skill)
- Activity description (skill)
- Task code (linking activity and cost codes)
- Percent completion (physical or fiscal) (current projects only)
- Scheduled start date (design start date required)
- Target finish date (design expected completion date required)

If conditions are extraordinary, the time allowed for an activity can be set to zero.

One exception to the sequence shown is Congress' passing of an appropriations bill. Appropriations may be approved prior to design completion; in this case, the time required for this activity is zero.

Generally, the time needed by the Corps' estimating, specifications, and reproduction offices and by potential contractors to process specifications and drawings is longer for complex projects than for simple ones. No time is required for Congressional action if appropriations are made prior to design completion. Amendment cutoff periods are often 14 days prior to bid opening. Advertising periods tend to be 1 month, with 2 months as the maximum. For small-business, set-aside contract awards, see ASPR Para. 1-705.

There are three sources of data for scaling the time required. Two sources, discussed in later chapters--"ER 415-345-43 Project Data Analysis" and "Fort Worth District MIDAS Project Data Analysis"--can be used to scale the entire process, but not individual activities. The third source consists of activity time estimates by the following Corps

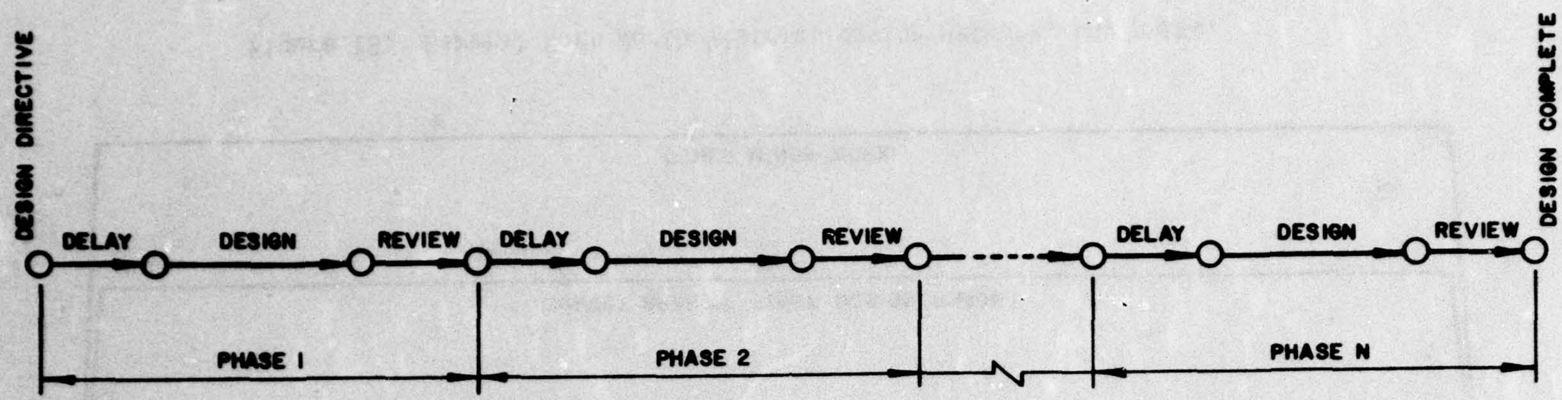


Figure 16. General design process network (preconstruction).

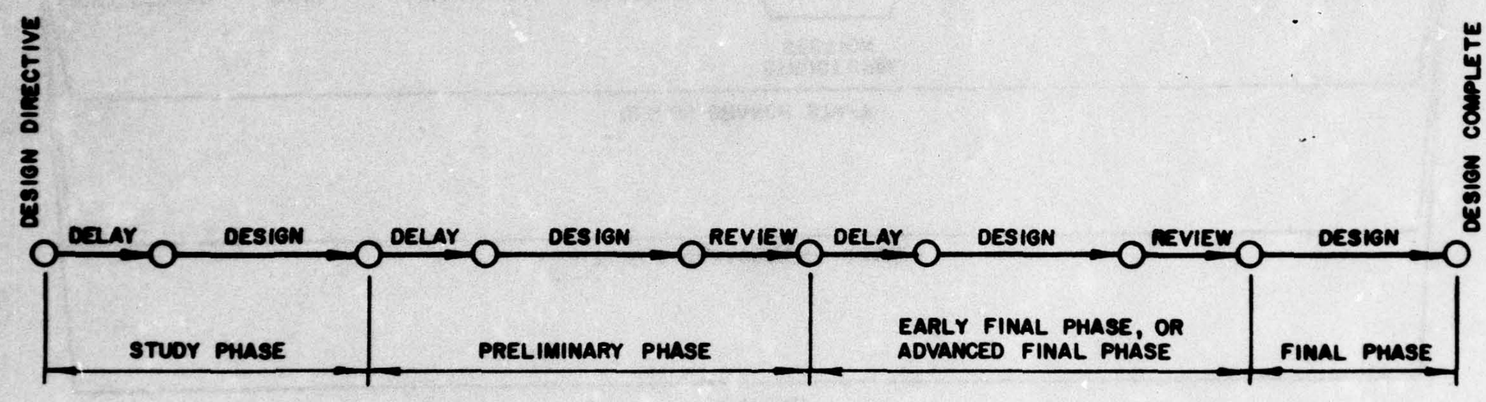


Figure 17. General Fort Worth District design process network.

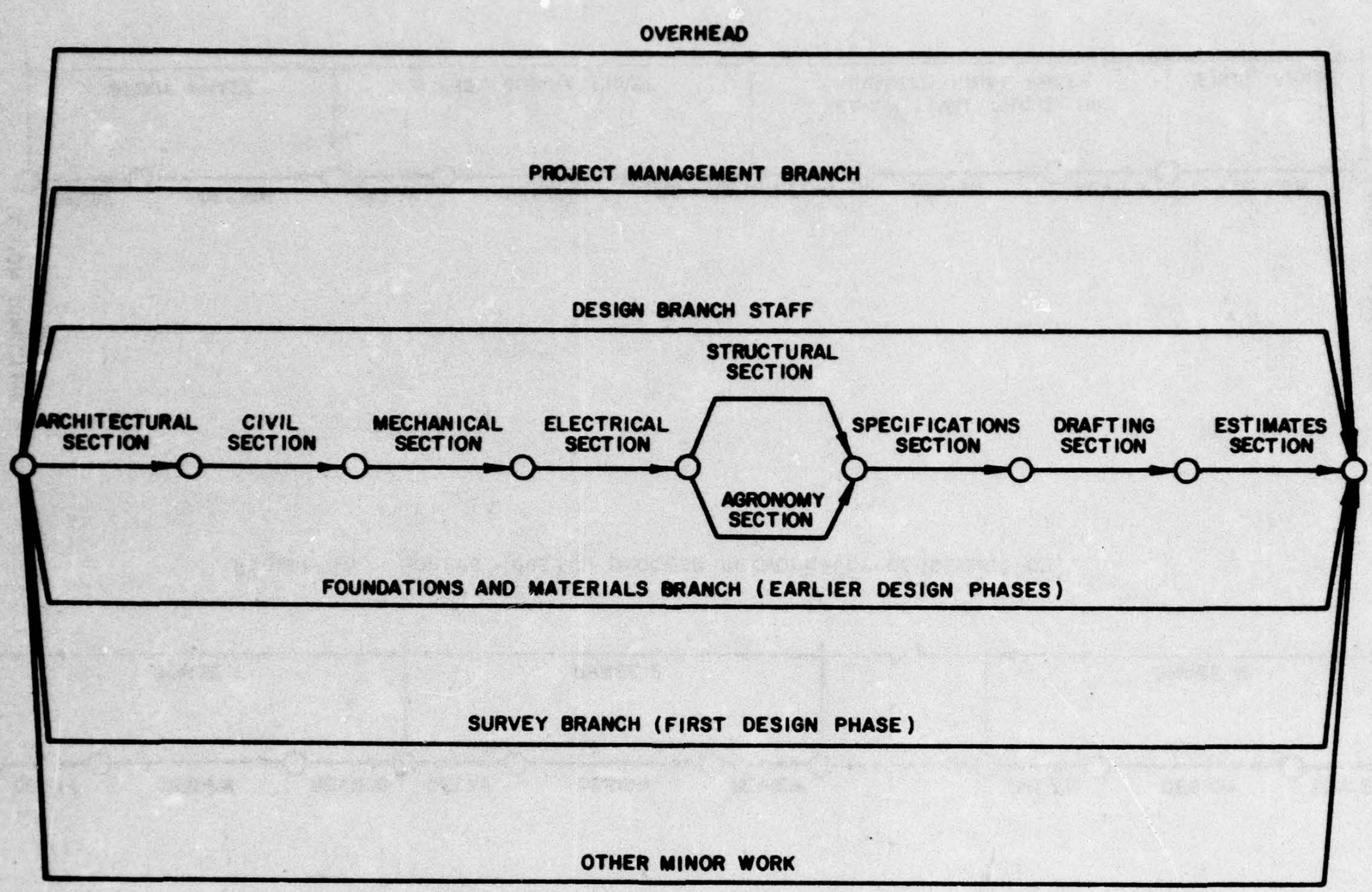


Figure 18. General Fort Worth District design network, any phase.

of Engineers offices having military design responsibility:

- HND U.S. Army Engineer Division, Huntsville
- MRO U.S. Army Engineer District, Omaha
- NAB U.S. Army Engineer District, Baltimore
- NAN U.S. Army Engineer District, New York
- SAM U.S. Army Engineer District, Mobile
- SAS U.S. Army Engineer District, Savannah
- SPK U.S. Army Engineer District, Sacramento
- SWF U.S. Army Engineer District, Fort Worth

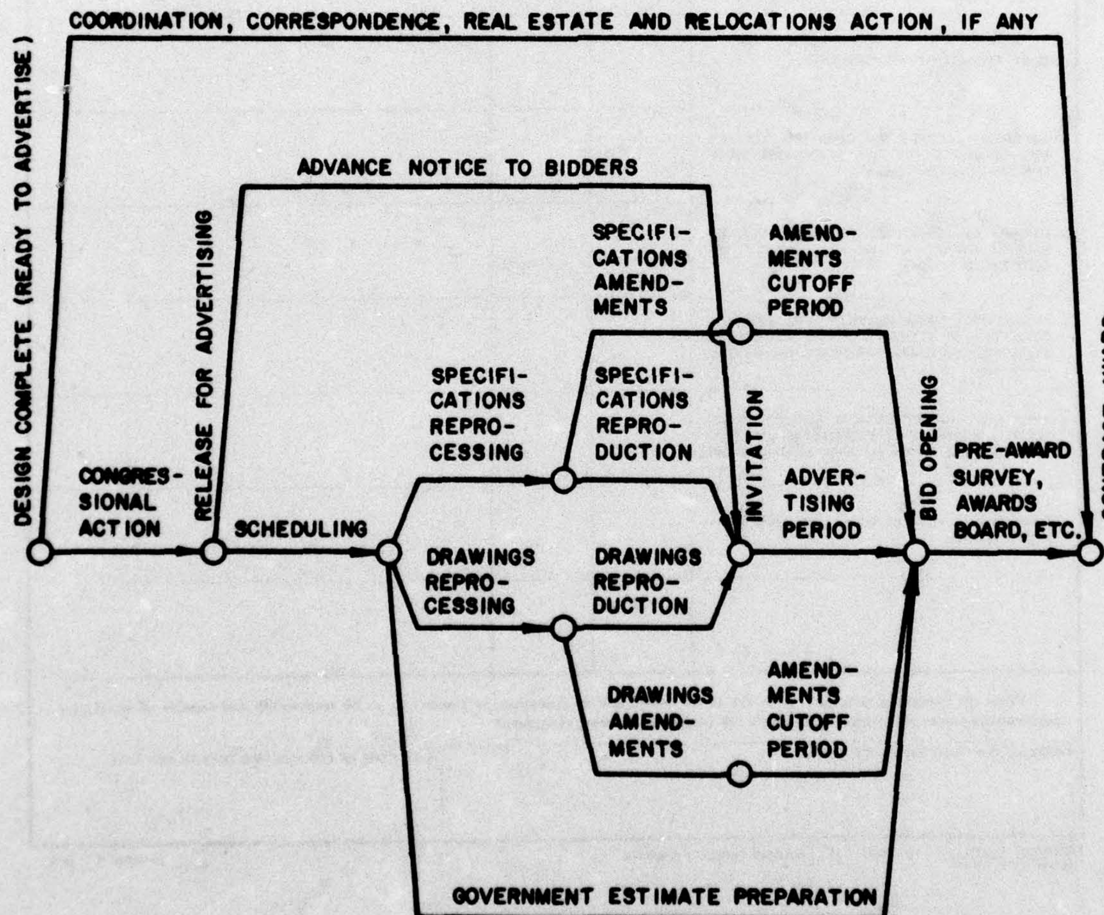


Figure 19. General advertisement and award process network.

PRE-AWARD SURVEY ARCHITECT-ENGINEER AND CONSTRUCTION CONTRACTS

(Refer to ASPR 1-900)

NAME OF A-E OR CONSTRUCTION CONTRACTOR

The following items, as applicable, have been considered in light of information known to the contracting officer and each item rated as shown.

ITEM	SATIS-FACTORY	QUESTION-ABLE	REMARKS
1. FINANCIAL ABILITY TO PERFORM THE CONTRACT, INCLUDING THE AVAILABILITY OF NECESSARY WORKING CAPITAL AND CREDIT.			
2. ABILITY TO COMPLY WITH THE REQUIRED OR PROPOSED DELIVERY OR PERFORMANCE SCHEDULE, TAKING INTO CONSIDERATION ALL EXISTING BUSINESS COMMITMENTS.			
3. BUSINESS AND FINANCIAL REPUTATION AND INTEGRITY.			
4. PAST RECORD OF PERFORMANCE.			
5. APPARENT ABILITY TO CONFORM TO THE REQUIREMENTS OF THE STANDARD NON-DISCRIMINATION CLAUSE.			
6. GENERALLY QUALIFIED AND ELIGIBLE TO RECEIVE AWARD UNDER APPLICABLE LAWS AND REGULATIONS.			
7. NECESSARY ORGANIZATION, EXPERIENCE, OPERATIONAL CONTROLS, AND TECHNICAL SKILLS TO PERFORM THE WORK *(or ability to obtain same)*.			
8. NECESSARY CONSTRUCTION AND/OR TECHNICAL EQUIPMENT AND FACILITIES FOR PERFORMING THE WORK *(or ability to obtain same)*.			
9. FURNISHING OF PERFORMANCE AND PAYMENT BONDS.			

From the foregoing ratings, I deem the above named A-E or Construction Contractor to be responsible and capable of satisfactory performance under the contract for which the contractor is being considered.

PROPOSED CONTRACT IDENTIFICATION	SIGNATURE OF CONTRACTING OFFICER AND DATE

ENG FORM 1 JUL 68 2459 *(ER 1180-1-1)* PREVIOUS EDITION IS OBSOLETE. 16—70780-1 GPO

Figure 20. ENG FORM 2459: Pre-award survey architect-engineer and construction contracts.

Construction Modification Design Process

There are construction contract modifications which require changes in plans and specifications. With the exception of user requests for changes during construction, the design changes arise from errors in the preconstruction engineering process. Design problems related to construction contract modifications, as indicated in Table 9, tend to be either administrative (coordination, using agency/service/command/installation, review, procurement, and timeliness problems) or technical engineering (design/drawings, specifications, and estimates problems).

Apart from resources of times, funds, and manpower directly consumed in the design modification activities, there are indirect resource demands arising from the disruption of construction activities. This phenomenon has been studied[11] and some quantitative data have emerged. Based on a study of 221 Army-constructed military facilities, construction time overruns averaged 25.3 percent of the time specified for the jobs. This sample was selected to be representative and not to consist of projects with overruns, although overruns were the rule. Of the 25.3 percent time overrun, 9.4 percent was chargeable to design errors, and 5.3 percent was chargeable to using agency change requests--a total of 14.7 percent chargeable to designers and design administrators. The other 10.6 percent was due to weather, strikes, late deliveries, and other causes.

Of course, design modifications can arise prior to construction contract award, e.g., during the design and advertisement and award phases. The procedure for handling design and modifications during the earlier phases is about the same. Construction activities may then require some rescheduling. During the advertising period, addenda to the plans and specifications must be issued to prospective bidders.

Network

Figure 21 is a general construction modification design process network. Not all of these activities will apply to a single project. Approvals above the District office level are rare (see Table 9).

Activity times are not indicated, because they are highly variable. However, certain positive statements can be made. Times for procurement actions tend to be shorter than those indicated in "Architect-Engineer Procurement and District Engineer Predesign Process." Design times should be similar to those indicated in "Design Process (Preconstruction)." It should be noted that design time only be estimated accurately in terms of the dollar volume of redesign, with personnel

[11] D. W. Halpin and R. D. Neathammer, *Construction Time Overruns*, Technical Report P-16/AD766725 (CERL, August 1973).

Table 9

Design Problems Related to Construction Contract Modifications
(repeated problems are in parentheses)

COORDINATION

Construction does not properly coordinate with Engineering prior to issuing changes.
Resident Construction Office should be allowed direct informal contact with District Counsel for informal advice on changes.
Engineering should be more cooperative in solving problems discovered during construction.
Site coordination/adaption of designs is inadequate.
Architect-Engineers should use field office personnel site knowledge.
Using agency change requests are not well coordinated with the Corps.
Field offices delay modification processing by not meeting district office submittal information requirements.
Overall field and district office coordination improvement would lower modifications cost.
Original designers should review proposed changes.
Architect-Engineers repeat mistakes because they do not follow jobs through the construction phase.
There is not a good system for eliminating repetitive design errors when first disclosed in construction.

USING AGENCY/SERVICE/COMMAND/INSTALLATION

Construction contract documents do not meet using agency requirements.
Using agency tries to change plans during construction.
Using agency change requests are not well defined.
Using agency change requests are not processed quickly.
Using agency creates too many change orders.
Using agency change requests after construction contract award often should have been made during or prior to design.
(Using agency change requests are not well coordinated with the Corps.)

REVIEW

Bid documents are not properly reviewed prior to advertisement.
Field offices are not given adequate time to review bid documents.

Table 9 (cont'd)

Field office comments are not incorporated into amendments.
Field personnel are not included in design review meetings.
Review time lengthened in coordinating an excessive number of design errors.

PROCUREMENT

Architect-Engineer firms with poor performance records continue to get new work.
Field offices do not have input to Architect-Engineer performance evaluation.

TIMELINESS

District office response to field office problems/questions is too slow.
Engineering Division correction of all design deficiencies is too time-consuming when field offices could correct same.
Advertising too many construction contracts in a short period causes workload problems for Corps personnel and bidders.
(Government estimates are not completed on a timely basis.)
(Using agency change orders are not processed quickly.)

DESIGN/DRAWINGS

Architect-Engineer designs do not properly incorporate OCE criteria.
Designers are unaware of code requirements and design-in conflicts.
Architect-Engineer designs are not of good quality.
(Site coordination/adaption of designs is inadequate.)
Drawings do not have adequate details.
Drawing requirements are not well coordinated.
Drawings contain too many errors, omissions, and conflicts.
Corps drawings are not working drawings and require extensive shop drawings prior to construction.
Standard drawings contain outdated and/or unreasonable requirements.

SPECIFICATIONS

Specifications are too complicated and hard to understand.
Specifications are not fully self-consistent or consistent with drawings.
Specifications contain outdated and/or unreasonable requirements.
Specifications are not specific regarding requirements.
Specifications are voluminous and/or contain extraneous information.
Specifications conflict with codes and specifications they reference.
Specifications are not correct for the area of construction.
Specifications are not correct for equipment exposed to the elements.
Specifications contain errors and omissions.

Table 9 (cont'd)

Specifications written around specific equipment cause problems.
Specifications changes are not well disseminated.
Specifications assembled in separate volumes for each building of a multi-building project are inefficient.
It is not obvious whether a given contract specification conforms to government guide specifications.

ESTIMATES

There is no standard government estimate preparation format.
Better estimate preparation guides are needed.
Government estimates are not completed on a timely basis.
Architect-engineer modification estimates are not corrected for location.
Requirement for revising government estimates is costly and often unnecessary.
Engineering Division estimates for changes are excessively low, causing funding problems.

availability as a constraint. Usually there is no change in project scope (e.g., square footage, linear feet, etc.), thereby eliminating consideration of a design-time scope relation.

The procurement process is not as complex for design modification as for original design. The checklist used to prepare a contract modification is ENG Form 3762-2 (Figure 22).

Design modification activities and their sequence are reasonably fixed. For reasons given below, the activities' existence and time consumed in performing them is highly variable.

Changes, Errors, Omissions, and Conflicts

A design modification arises from a construction contract modification which requires a significant change in plans or specifications. Not all construction contract modifications require redesign. A change request can originate with the using agency/service/command/installation after construction contract award. Design errors can be discovered by government or contractor field personnel during construction. An error may be caused by an omission, inclusion of something unnecessary, or an incorrect requirement. Sometimes drawings and specifications are not internally consistent or consistent with one another, i.e., conflicting. More often than not, the major time consumed in the modification process is administrative, as contrasted with design engineering. All of this affects the actual construction activities, often resulting in construction time overruns.

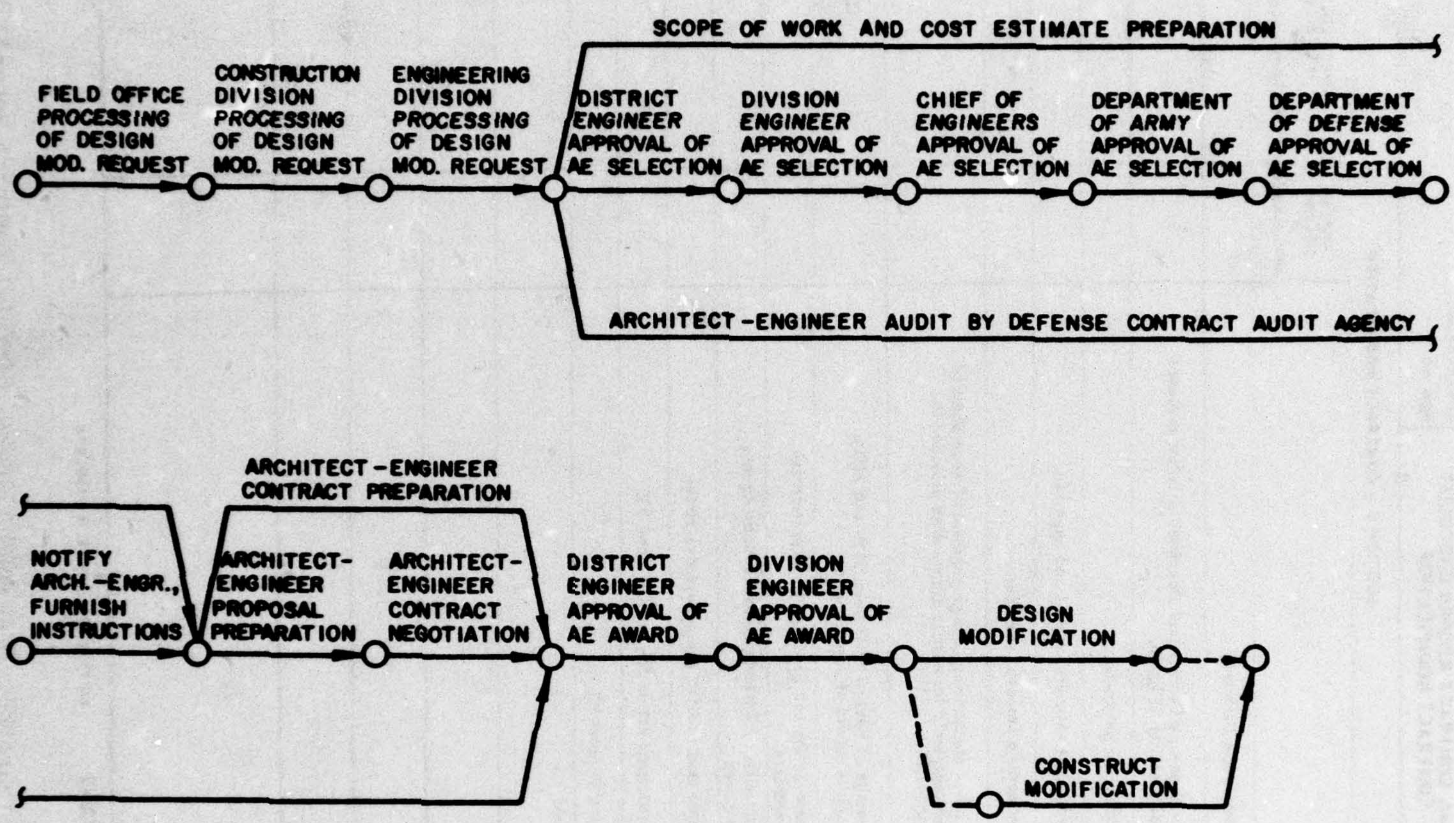


Figure 21. General construction modification design process network.

OFFICIAL CONTRACT RECORD CHECKLIST - CONTRACT MODIFICATION	CONTRACT NO. MOD. NO.	

SECTION C - CONTRACT MODIFICATION

TAB	ITEM	CHECK COLUMN IF APPLICABLE	CHECK COLUMN IF IN FILE OR WRITE IN LOCATION
	1. Memorandum Directive.		
	2. Miscellaneous Commitment Document or other evidence of availability of funds.		
	3. Request for proposals.		
	4. Government estimate, signed and approved.		
	5. Contractor's proposal and cost data.		
	6. Rejected engineering change proposals (these shall be filed separately for earlier disposal as provided in S2-501(v)).		
	7. Findings of Fact or ENG Form 2180 and 2180a. Complete record of negotiations.		
	8. Determination and Findings for Supplemental Agreements.		
	9. Evaluation by Defense Contract Audit Agency, if required.		
	10. Signed modification and acceptance letter.		
	11. Procurement action Report, DD Form 350.		
	12. Notice to proceed.		
	13. Other: a.		
	b.		
	c.		
	d.		

ENG FORM SEP 67 3726-2 EDITION OF 1 APR 66, IS OBSOLETE.

Figure 22. ENG FORM 3726-2: Official Contract Record Checklist - Contract Modification.

Decision to Design In- or Out-of-House

When the Corps District office construction division informs the District office engineering division that a design change is required, the engineering division must decide whether to do the work in-house or by contract. The decision is affected by the complexity of the change, availability of in-house staff, and whether the original design was done by District forces or an A/E firm. A decision to do the work out-of-house involves a procurement process with its attendant actual and potential activities, listed below.

1. Procurement Activities--Actual

a. Government scope of work and cost estimate preparation

b. A/E proposal preparation

c. Contract modification negotiation

d. Government contract document preparation, District approvals, notice of award

e. Modification design construction.

2. Procurement Activities--Potential

a. Audit by Defense Contract Audit Agency if modification cost exceeds $100,000 [ASPR 3-801.5(b)(1)].

b. Award approval by Division Engineer if modification cost exceeds $100,000 (EC 1180-10140).

c. Award approval by Division Engineer if basic contract plus all modifications now exceed $500,000 (EC 1180-1-140).

d. Selection approval by Division Engineer if all basic contracts and all modifications to be awarded to one firm by the field contracting office now exceed $100,000 for the current calendar year [ASPR 18-402.3(ii)].

e. Selection approval by the next higher level when the supplemental agreements (not an administrative change or accomplished under the contract changes clause) added to the basic contract cost now exceed approval authority of the previous highest approval level [ASPR 18-402.3(vi)]. The changes clause is governed by ASPR 7-607.3.

f. Selection approval by the Assistant Secretary of Defense (Installation and Logistics), or his designee [the Deputy Assistant Secretary of Defense (Installations and Housing)], when the supplemental award is more than $200,000 and the basic contract is more than $1 million [ASPR 18-402.3(viii)].

g. Selection approval by the Assistant Secretary of Defense (Installations and Logistics), or his designee [the Deputy Assistant Secretary of Defense (Installations and Housing)], when the total fees to be awarded one firm by a Department within a single region or area now exceed $1 million for the current calendar year [ASPR 18-402.3 (ix)].

Design Complexity

The complexity of changes to plans and/or specifications affects the design time and cost. The procurement time can be affected when design modifications are performed out-of-house. All of this can add up to considerable construction delay.

Design and Construction Concurrency

To reduce construction time overruns, the design and construction modifications can be, and sometimes are, conducted concurrently.

3 ACTIVITY COST AND DURATION ANALYSIS

Goal of Analysis

The analysis of the cost and durations required for various design activities can be useful in two ways. First, high resource requirements and lengthy activities can be identified. Since the goal of this study is to effectively analyze the E&D process, it is logical that major problem areas and correspondingly potential improvements should be related to these activities. The analysis would identify candidate activities to be examined in detail. The second reason for activity cost and duration analysis is to develop a predictive means of estimating time and resource requirements for new projects based on historical records.

Three sets of data were examined: 285 Fort Worth projects for which gross design records existed; 70 Fort Worth projects with detailed design records; and 7500 project records of ER 415-345-43 (Military Design and Construction Progress Reporting).

Regression analysis was used to determine the relationships between design activities and time and/or effort. The importance of project identifiers was also evaluated analytically.

Fort Worth District MIDAS Project Data Analysis

The Fort Worth District furnished 285 sets of project time and cost data, which were constructed from the Management Information and Decision Analysis System (MIDAS). Detail was available from the MIDAS data base for the time consumed by each of the nine periods shown in Figure 17 and the succeeding advertisement and award phase. There are four active design periods: study, preliminary, advance final or early final, and final; the last three correspond to more detailed data analyzed in Chapter 4. The study, three delay, and two review periods are complementary to the grosser level of detail data provided in the next section (ER 415-345-45 Progress Reporting Data). The 285 projects furnished were those remaining after a number of checks to edit for consistency. Each project record is contained in an 80-column card, as shown in Table 10; the table indicates the method by which the data were obtained; actually, computation of the ten periods was a little more complicated, requiring approximately 200 executable FORTRAN statements. The cost figures spanned the fiscal years 1969 to 1977; costs were adjusted to a base year 1974. No adjustments to scope data were made.

The 285-project sample is not large in some respects. A broad range of facility classes and construction categories was included, which allowed only heterogeneous analysis. As would be expected, not all design periods were reflected in all projects. A few projects were studies only, and only a few projects having preliminary and/or advanced final and/or final design had a study period. A project could have neither a study nor a preliminary design or it could have final design

Table 10

Project Design Period Records - 80-Column Card Format

Item	Cols	Symbol	Data Element Name	MIDAS Data Element
1	1-5	FC4	Facility Class and Construction Category Code	12 Category Code
2	6-10	BASE	Installation Code	Header Station Code
3	11-25	TITLE	Project Description	Header Descr
4	26-29	PROG	Type Funds Code	10 OCE Item Code
5	30-31	FY	Fiscal Year	4 Program FY
6	32-33	DBY	Designed by (HL or AE)	17 Designed by
7	34-35	TYPE	Type Design	23 Design Method
8	36-41	SCOPE	Numeric Value of UM	14 Auth Scope
9	42-43	UM	Unit of Measure	14 Un Meas
10	44-50	DESCST	Design Cost, Total, $	27 Tot Engrg Design Cost
11	51-53	DELAY	Project Start Delay Time (All times are in calendar days)	(Earliest of Either) 50 Study Start Date, or 53 Prelim Start Date, or 60 Final Start Date, less 11 Directive No/Date
12	54-56	STUDY	Study Design Phase Time	51 Study Compl Date, less 50 Study Start Date
13	57-59	DELAY2	Study-Preliminary Delay Interphase Time	53 Prelim Start Date, less 51 Study Completion Date
14	60-62	PRELIM	Preliminary Design Phase Time	55 Prelim Fwd Date, less (if 55 $\neq$ 0, or) 58 Prelim Aprov Date, less 53 Prelim Start Date
15	63-65	CHECK1	Preliminary Design Review Time	58 Prelim Aprov Date, less 55 Prelim Fwd Date
16	66-68	DELAY3	Preliminary-Advanced Final Delay Interphase Time	60 Final Start Date, less 58 Prelim Aprov Date

Table 10 (cont'd)

17	69-71	ADVFIN	Advanced (or Early Final) Design Phase Time	61 Final Due Date, less (if 61 ≠ 0, or) 62 Final Fwd Date, less 60 Final Start Date
18	72-74	CHECK2	Advanced (or Early Final) Design Review Time	66 Final Aprov Date, less 62 Final Fwd Date
19	75-77	FINAL	Final Design Phase Time	67 Design Compl Date, less 66 Final Aprov Date
20	78-80	ADVAWD	Advertisement and Award Phase Time	107 Constr Contr Awd Date, less 67 Design Compl Date

only. Fewer projects were scheduled for advertisement and award than expected. A number of projects had a recorded negative time for the project start delay time. There are three possible explanations: (1) a misunderstanding about whether the directive date was to be the date of the earliest design directive, not the date of one of the later design directives, or (2) design was initiated prior to receipt of a directive, or (3) an error was made in recording the data. Of these three, the first and the last seem most likely. A breakdown of the 285 projects by time periods covered is given below, excluding the two review periods and last two delay periods during which reviews and delays are closely associated with their respective preceding active design periods.

Projects	Time Period Greater Than Zero
265	Project start delay time
35	Study design period time
163	Preliminary design period time
255	Advanced (or early) design period time
135	Final design period
137	Advertisement and award period

Implicit in the data is an eleventh time period for A/E procurement and for District engineer predesign activities. The time for this eleventh period can be estimated crudely by calculating the difference in project start delay time between projects designed by contract and projects designed by District forces.

Regression Criteria

The desired end result of the data analysis was to determine: design time as a function of design cost, design time as a function of scope, the fractional amount of total design time consumed by each component design period, and the influence of factors such as A/E vs. District engineer design and original vs. standard design. After reviewing the quality of the data and quantity of information available for related facility classes and construction categories, it did not seem possible to derive time-scope relations. Advertisement and award time, as related to design time and design cost, is a separate consideration.

Time periods require careful grouping for analysis for two reasons: (1) a particular design may be study only, final design only, or have no study and preliminary design, and (2) the source data often appear to lack the later time period records. Two approaches could then be taken to analyze the data: (1) projects with like time periods throughout the design could be considered together, or (2) projects with similar time period groups could be considered together. The latter approach was adopted. The objections to the first approach are: resultant small sample sizes, multiplicity of analyses, and difficulty in interpreting results of analyses. The time period groups selected were:

(1) Total Design Time. The sum of nine individual periods; four active design, two review, and three delay.

(2) Total Design Time. The sum of four time period groups: (1) project start delay, (2) study and succeeding delay, (3) preliminary, succeeding review, and succeeding delay, and (4) advanced or early final, succeeding review, and final.

(3) Total Design Time. The sum of three time period groups: (1) four active design, (2) two review, and (3) three delay.

(4) Total Active Design Time. The sum of four individual periods: study, preliminary, advanced or early final, and final.

(5) Total Design Review Time. The sum of two individual periods: reviews following preliminary and advanced or early final.

(6) Total Design Delay Time. The sum of three individual periods: project start delay, delay before preliminary, and delay before advanced or early final.

(7) Project Start Delay. One period, if project start delay exists.

(8) Study Design Time and Delay. Two periods, if study exists.

(9) Preliminary Design Time, Succeeding Review, and Delay. Three periods, if preliminary design exists.

(10) Advanced or Early Final Design Time, Succeeding Review, and Final Design Time. Three periods, if advanced or early final design exists.

(11) Final Design Time. One period, if final design exists.

(12) Advertisement and Award Time. One period, if advertisement and award exists.

Of the 12 time groups listed, three involve total design time. Consequently, 10 time-cost relations were sought. Total design cost was the independent variable. Polynomial curve fitting was used in the calculations, except for an additional exponential curve fit for total active design time. Total design time and total active design time were investigated for quartic, cubic, quadratic, and linear cost relations. Additionally, total active design time was investigated for the expression $K_1[\exp(-C/M] + K_2$, where: C is the project total design cost, M is the mean total design cost (taken as $50,000), and K_1 and K_2 are constants determined by regression. All other time groups were investigated for quadratic and linear cost relations. Usually, very little additional accuracy was gained by fitting a higher order equation such as a cubic or quartic.

Regressions were run to establish time-to-time and time-to-cost relations for five groupings of projects: all 285 projects, 200 A/E projects (DBY=AE), 79 District engineer projects (DBY=HL), 208 original designs (TYPE=OR), and 77 nonoriginal designs (TYPE≠OR). The entire group of 285 projects can be considered a control. The 200 A/E projects and 79 District engineer projects fall six short of 285; there were two using service designs and four undesiganted designs. Ideally, the nonoriginal designs would consist primarily of short design-time projects involving standard drawings and/or site adaptations. Actually, the nonoriginal designs were mixed: 20 standard, 22 site adaptation, 8 rehabilitation, 8 special, 3 definitive, and 16 undefined. Contrary to expectation, the standard designs consumed about the same time, on the average, as the original designs.

Regression Results

Tables B1 through B5 in Appendix B show the results of the time and cost regressions on the five project groupings. For all regression models, the correlation of individual time periods to total design time was low, implying that based on total time required, these models are, at best, marginally good predictors of individual design times. Appendix B also presents the ratio of standard deviation to mean time for the five principal groups (Table B6) and the results of time versus cost regressions in terms of means and standard deviations (Table B7).

Table 11 presents the mean design times for the five principal groups of projects. The groups are ordered from largest to smallest number of sample projects. As would be expected, the first three groups, which have many projects in common, tend to be similar. When

Table 11

Time Regression Results - Adjusted Costs
Mean Times

Total Design Time Design Time Group Design Period	285 (All) Projs	208 Original Des Proj	200 AE Projs	79 DE Projs	77 Non-Original Des Proj
Total Design Time*	421	430	422	393	397
Total Active Design	169	175	156	206	152
Study	12	12	10	16	10
Preliminary	47	44	47	51	55
Advanced (or Early) Final	84	91	77	102	66
Final	26	28	22	37	21
Total Design Review	50	54	56	38	39
Preliminary	28	30	32	20	24
Advanced (or Early) Final	22	24	24	18	15
Total Design Delay	202	201	210	149	206
Project Start	176	179	179	131	168
Before Preliminary	16	13	19	10	24
Before Advanced Final	10	9	12	8	14
Total Design Time*	421	430	422	393	397
Project Start Delay	176	179	179	131	168
Study Delay	28	25	29	26	34
Preliminary, Review, Delay	85	83	91	79	93
Advanced Final, Review, Final	132	143	123	157	102
Total Design Time	456	445	455	422	493
Project Start Delay	196	190	199	144	215
Total Design Time	421	389	416	428	468
Study and Delay	160	155	182	128	169
Study Design	94	122	97	91	54
Delay Before Preliminary	66	33	85	37	115
Total Design Time	473	523	468	496	366
Preliminary, Review, Delay	150	156	140	189	138
Preliminary Design	82	83	72	122	82
Preliminary Review	49	55	49	49	36
Delay Before Advanced Final	19	18	19	18	20
Total Design Time	440	426	449	391	487
Advanced Final, Review, Final	143	145	134	169	136
Advanced Final Design	94	95	88	111	88
Advanced Final Review	20	21	22	20	19
Final Design+	29	29	24	38	29
Total Design Time	515	491	501	482	591
Final Design	55	56	44	84	52
Total Design Time	367	392	359	398	283
Advertisement and Award	116	122	127	92	96

* Not all of the activities necessarily occurred for each sample project. Can be used as an estimate for a job if uncertainty exists as to whether all activities are required.

\+ Did not necessarily occur for each sample job. See above for use.

comparing A/E and District Engineer (DE) projects, four factors are striking: (1) the total active design time is less for A/E than for DE projects, although the DE projects involve slightly less money; (2) the total review time is more for A/E projects; (3) the total delay time is more for A/E projects, especially project start delay; and (4) the total design time, given all nine design periods, is about the same for A/E (199 + 97 + 85 + 72 + 49 + 19 + 88 + 22 + 44 = 675 days) as for DE (144 + 91 + 37 + 122 + 49 + 18 + 111 + 20 + 84 = 676 days). The explanations would seem to be: (1) the project daily rate of expenditure (crew size) is less for DE; (2) the DE review of in-house work is more continuous, due to a greater rapport between designers and reviewers when both are in-house; (3) the difference in project start delay--55 days--results from the A/E procurement process; and (4) the same overall performance standard is being used for both A/E and DE projects. The total design time, given all nine design periods, is about the same for the original designs (190 + 122 + 33 + 83 + 55 + 18 + 95 + 21 + 56 = 376 days) as for the nonoriginal designs (215 + 54 + 115 + 82 + 36 + 20 + 88 + 19 + 52 = 681 days). If the preliminary, advanced final, and final periods are summed and averaged for the standard designs and site adaptations, the average times are 188 and 139 days, respectively, compared with 163 = (44 + 91 + 28) days for the original designs. The sum of the mean times, if all nine design periods occur, for the five groups of projects are 675, 673, 675, 676, and 681 days, respectively.

As noted earlier, only 256 of the 285 projects had nonzero project start delay times. The other 29 projects had negative delay times which were reset to zero. Thus, the average project start delay for 285 projects is probably greater than 176 days. Six of the project start delays were 1000 or more days and were reset, arbitrarily, to 999 days. Thus, the project start delay of 196 days for 256 of 285 projects may be conservatively low, if there were no errors in the source data. One advanced final review period was 1000 or more days and represented approximately 20 percent of the total advanced final review time. On the other hand, in almost half the projects for which there was advanced final design recorded, no advanced final review time was recorded. Consequently, advanced final review time is probably understated. One project having negative final design time did not have final design time reset to zero. This resulted in less than a 1 percent error in final design time calculations.

It is to be expected that design time and design cost relations, as given by data analysis, are not always reliable. The problem is in the source data. Consider that most jobs are subject to a design limit of 6 percent of the construction cost; not all such jobs can be designed for 6 percent. As a result, some projects which can be done for less than the limit (standard designs and site adaptations) will accrue design charges for projects which go over the limit. Consequently, design-time construction-cost and design-time scope relations may be more realistic than design-time design-cost relations for some types of design.

Explicit time-cost functional relations will be discussed in the Fort Worth District Detailed Project Data Analysis section. Time-cost relations obtained for the five principal sets of regressions mentioned previously were stronger for active design periods and weaker for review periods, delay periods, and advertisement and award, as would be expected. No project startup discrimination between large and small projects was apparent, i.e., there was no evident higher priority for large, high-visibility projects.

Table 12 shows the effect of adjusting design costs to a common base year (calendar year 1974 was used). The top half of the table shows the method of cost adjustment and resulting cost indices used in cost conversion. Ideally, better design-time design-cost correlations should be obtained with costs adjusted to be time independent, providing that the times and costs are related. The bottom half of the table shows the results with and without adjustment in terms of design-time design-cost correlation coefficients. (The adjusted cost correlation coefficients, R, are the same R values which appear in the rightmost column of Table 12). There is no significant difference in the two sets of coefficients, contrary to what would have been expected.

Fort Worth District Detailed Project Data Analysis

Seventy sets of project cost and time data have been supplied by the U.S. Army Engineer District, Fort Worth (SWF). The data have been constructed from in-house design financial records and reflect activities which resulted in project charges. Detail is available at the branch and section levels. Figure 19 provides general SWF design network for any design phase (either preliminary, early final, advanced final, or final). An entire project design network would contain one to four such phase networks in sequence. Typically, the source data appear as shown in Figure 23--one header card, three time cards, and four cost cards per project. Descriptions of the data elements (variables) are underlined in the figure. Beneath the written descriptions are the assigned variable names, and beneath each variable name is the data item value for the given project. Figure 24--a listing of project header cards by facility class and construction category--indicates the variety of data. The 70 projects are those which met a number of edit checks for consistency. For 70000-series facility class projects having scope expressed in terms of men, scope has been converted to square feet by factors of 127.5 sq ft (11.9 m^2) per enlisted man and 440 sq ft (41 m^2) per officer. Since most of the projects were designed over an 18-month interval, there was no need to adjust cost to a common base year. The source data, which are expressed as activity percent cost of total design cost, must be converted to dollar cost (multiplied by design cost and divided by 100) prior to a regression analysis.

Regression Criteria

The desired end result of the analysis was a determination of: design times as a function of design cost, design time as a function

Table 12

Regression Results - Cost Index Adjusted Cost vs. Unadjusted Costs - All 285 Projects

Conversion Routine: Base Year 1974

Calendar Year	Index, 1967 Base Year	Index, 1974 Base Year	Fiscal Year	Index for Fiscal Year
1968	106	173/106		
1969	114	173/114	1969	173/110
1970	122	173/122	1970	173/118
1971	130	173/130	1971	173/126
1972	139	173/139	1972	173/134.5
1973	152	173/152	1973	173/145.5
1974	173	173/173	1974	173/162.5
1975	190(Est)	173/190	1975	173/181.5
1976	207(Est)	173/207	1976	173/198.5
1977	224(Est)	173/224	1977	173/215.5

Regression Correlation Coefficients: Time with Total Design Cost

Time Component	Adjusted Cost Correlation	Unadjusted Cost Correlation
Total Design Time	.38	.38
Total Active Design Time	.52	.53
Total Design Review Time	.18	.18
Total Design Delay Time	.11	.10
Project Start Delay Time	.03	.01
Total Study and Delay Time	.22	.21
Total Prelim, Review, Delay Time	.33	.30
Total Adv Fin, Review, Final Time	.34	.33
Final Design Time	.21	.22
Advertisement and Award Time	-.10	-.10

```
PROJECT HEADER DATA
-------------------

FACILITY                         CONTROL  DESIGN DESIGN TYPE SCOPE,     TYPE  DSGN
CLASS PROJECT DESCRIPTION        COST, $     $      %  DESIGN UNITS UM FUND FY BY
----- -------------------- --------- ------- ---- ----- ------ -- ---- -- --

 FC4         TITLE           PRGAMT   DESCST DESPCT TYPE  SCOPE UM PROG FY DRY

72110 BARRACKS MODIZATION    5716000  102355  2.0 ORIG  285600 SF MCA  74 ML

TIME DATA, IN WORKING DAYS (DESIGN BRANCH, LESS BRANCH STAFF)
-------------------------------------------------------------

SECTIONAL TIME DATA, DESIGN BRANCH
----------------------------------

 BRANCH  ARCHI-             ELEC-   ESTI- MECHAN- SPECIFI- STRUC-
  STAFF TECTURAL  CIVIL   TRICAL  MATING   ICAL  CATIONS  TURAL  DRAFTING
 ------  ------  ------   ------  ------  ------  ------  ------  ------

PRELIMINARY DESIGN PHASE
------------------------

  BPT     APT     CPT     EPT     TPT     MPT     PPT     SPT     DPT

          24.1    14.2    20.7    30.8    63.9    0.0     17.2    83.0
ADVANCED (OR, EARLY) FINAL DESIGN PHASE
---------------------------------------

  BAT     AAT     CAT     EAT     TAT     MAT     PAT     SAT     DAT

          9.3     15.2    60.3    37.6    21.1    23.2    11.4    2.7
FINAL DESIGN PHASE
------------------

  BFT     AFT     CFT     EFT     TFT     MFT     DFT     SFT     DFT

          6.2     7.5     12.0    30.8    21.2    5.6     5.8     1.3

COST DATA, IN PERCENT FRACTION OF TOTAL DESIGN COST
---------------------------------------------------

BRANCH COST DATA, ENGINEERING DIVISION
--------------------------------------

PROJECT CONTRACT                   FOUNDS
 MGMT    (A/E)   DESIGN  SURVEY   + MTLS OVERHEAD OTHER
------  ------   ------  ------   ------  ------  ------

 PMC     AEC      DRC     SRC      FMC     OMC     ETC

 8.8     0.      68.4     0.        .2    12.0    10.6
SECTIONAL COST DATA, DESIGN BRANCH
----------------------------------

 BRANCH  ARCHI-             ELEC-   ESTI- MECHAN- SPECIFI- STRUC-
  STAFF TECTURAL  CIVIL   TRICAL  MATING   ICAL  CATIONS  TURAL  DRAFTING
 ------  ------  ------   ------  ------  ------  ------  ------  ------

PRELIMINARY DESIGN PHASE
------------------------

  BPC     APC     CPC     EPC     TPC     MPC     PPC     SPC     DPC

 1.8026  5.9956  0.9013 10.6197  1.9985 11.4476  0.      1.4107  5.0159
ADVANCED (OR, EARLY) FINAL DESIGN PHASE
---------------------------------------

  BAC     AAC     CAC     EAC     TAC     MAC     PAC     SAC     DAC

 2.2242  1.0821  1.2023  5.3101  2.7452  2.8454  2.6450  0.9418  1.0420
FINAL DESIGN PHASE
------------------

  BFC     AFC     CFC     EFC     TFC     MFC     PFC     SFC     DFC

 0.8889  0.5499  0.5957  1.0630  1.9978  2.8501  0.5315  0.4765  0.2108
```

Figure 23. Typical project data.

FACILITY CLASS	PROJECT DESCRIPTION	CONTROL COST, $	DESIGN $	DESIGN %	TYPE DESIGN	SCOPE, UNITS	UM	TYPE FUND	FY	DSGN BY
11111	EXT PAVED OVERRUN	133000	16016	13.4	ORIG	7633	SY	MCAF	74	HL
11130	HELIPADS LANDNG AREA	2464000	112377	5.1	ORIG	138170	SY	MCA	73	HL
11221	TAXIWAY	371000	37906	11.4	ORIG	18625	SY	MCAF	74	HL
11221	TAXIWAY	711000	48137	7.5	ORIG	43000	SY	MCAF	71	HL
11661	ARM/DISARM PADS	237000	16820	7.9	ORIG	14000	SY	MCAF	74	HL
11666	PWR CK PAD W/SUPORS	267000	20830	8.7	SPEC		DL	MCAF	74	HL
13111	BASE COMM ADDIT	150000	45744	33.9	STD	3000	SF	MCAF	72	HL
13430	APPROACH ILS ROH G2	1903000	52889	3.1	ORIG		DL	MCA	74	HL
13666	RUNWAY APPROCH LTG	480000	27426	6.3	ORIG		DL	MCAF	73	HL
13666	RUNWAY LIGHTING	809000	54166	7.4	ORIG		DL	MCAF	74	HL
14160	WEATHER FAC	85300	23299	30.3	ORIG		DL	MCA	70	HL
14996	DUCT FR CONT TWR B O	163000	11122	7.6	ORIG		DL	MCAF	72	HL
17950	FIRE RANGE	133000	14856	12.4	STD		DL	ARNG	74	HL
21110	HANGER W/ SHOPS	1313000	81034	6.9	ORIG	41920	SF	MCA	73	HL
21210	ADD FAC GM MAIN BLDG	600000	65327	12.1	ORIG	14150	SF	MCA	70	HL
21800	AREA B MAINT BLDG	138000	18579	14.9	ORIG	10150	SF	PEMA	74	HL
21800	AREA B LMBR & STG RD	249000	19159	8.5	ORIG		DL	PEMA	74	HL
22690	TRACK EXTENSION	42000	7239	19.1	ORIG	800	LF	PEMA	74	HL
22690	BLDG WASH MELT P EQ	17000	12738	83.3	ORIG		DL	PEMA	73	HL
22690	REPL TRANS OFFICE	296823	30899	11.6	ORIG		DL	PEMA	73	HL
31000	AREA SUPPORT BLDG	374000	22834	6.8	NONE	864	SF	NONE	74	HL
31040	RF VII DRY SITE ADDN		16821		ORIG		DL	MCA		HL
39040	RF VII OPT SUP FAC		22505		ORIG		DL	MCA		HL
39090	RF VII KING I ADDN		14805		ORIG		DL	MCA		HL
39090	DIST OPT ATT MEA SYS	530000	35976	7.5	STD		DL	MCA	73	HL
39090	RF VII RANGE POWER	178027	150313	93.8	ORIG		DL	MCA	72	HL
41113	AIRCRAFT FUEL STR FA	554000	37910	7.6	ORIG		DL	MCAF	73	HL
42280	EXT RR DOCK S COVER	193400	20654	11.9	SPEC		DL	PEMA	75	HL
45110	STG AREA ROADS	240067	24882	11.5	ORIG		DL	PEMA	73	HL
45210	CONC PAD IN STG AREA	115784	14570	14.0	ORIG		DL	PEMA	73	HL
72110	BARRACKS MODIZATION	5716000	102355	2.0	ORIG	2240	MN	MCA	74	HL
72110	BARRACKS MODIZATION	9212000	320555	3.9	ORIG	2814	MN	MCA	74	HL
72120	BARRACKS MODIZATION	371000	14820	4.4	ORIG	160	MN	MCA	74	HL
72290	LATRINES FOR RANGES	455000	16889	4.1	ADAPT		DL	MCA	74	HL
72410	BKS & BOQ REHAB PROJ	1342000	55598	4.6	ORIG	60	MN	MCA	70	HL
72410	AIR COND 6 BOQ S	1332000	70043	5.8	STD		DL	MCA	74	HL
72410	300 MAN BOQ	3683000	148050	4.5	ADAPT	300	MN	MCA	72	HL
74021	ADD TO MAIN COMM	894000	57116	7.1	ORIG	36064	SF	DASA	71	HL
74028	FIELD HOUSE	2384000	161685	4.6	STD	62000	SF	MCA	73	HL
74059	FIELD HOUSE	2600000	129840	5.5	ORIG	14150	SF	MCA	74	HL
74068	EM SERVICE CLUB	1283000	87358	7.6	ORIG	27800	SF	MCA	74	HL
74090	SP SER FAC BLDG	1140000	79928	7.8	ORIG	27200	SF	MCA	73	HL
81190	AUXIL GENERATORS	83753	14680	19.5	ORIG		DL	PEMA	74	HL
81190	EMERGENCY POWER	220224	26940	13.6	ORIG		DL	PEMA	73	HL
81230	STREET LIGHTING	54397	21613	44.1	ORIG		DL	PEMA	73	HL
81240	REPL PRIM DIST SYS	209000	13475	7.2	ORIG		DL	PEMA	74	HL
83130	WASTE WTR TRTMT FAC	105000	22519	23.8	SPEC		DL	MCA	72	HL
83190	WPC MONITOR STATION	50000	10094	22.4	STD		DL	MCA	74	HL
83190	WATER POLLUT ABAT	248000	23541	10.5	PRIOR		DL	MCA	73	HL
84130	WATER WELL ADDN	101048	5701	6.3	ORIG		DL	PEMA	72	HL
84210	WATER MAIN	76000	7637	11.2	ORIG		DL	ARNG	74	HL
84290	PROCESS WTR SYS A Y	33653	5530	18.3	ORIG		DL	PEMA	73	HL
85110	REPAIR ROADS & PKING	270000	13093	5.4	ORIG		DL	PEMA	74	HL
85130	SURFACE RNG ROAD	72000	7453	11.5	ORIG		DL	ARNG	74	HL
85130	STAR SEAL ROAD	92000	9695	11.7	ORIG		DL	ARNG	74	HL
85210	SURFACE T & LTG PK	547900	13887	2.2	SPEC		DL	PEMA	75	HL
85226	VEHICLE PKG COMM VEH	418000	20230	5.3	ORIG	51550	SY	MCAF	73	HL
86030	MODERN RR OVERPASS X	1010991	24377	3.2	ORIG		DL	PEMA	75	HL
86090	EXTEND RR FAC	19302	5723	32.9	ORIG	200	LF	PEMA	73	HL
86090	MOD TO BARRICADE	71000	7076	11.1	ORIG		DL	PEMA	73	HL
86090	RR DOCK EXT & COVER	13733	11553	93.5	ORIG	47689		PEMA	73	HL
86090	EXT RR DOCK & COVER	93400	12169	14.5	ORIG		DL	PEMA	73	HL
87190	SPRINKLER SYS A Y	92308	9000	10.8	ORIG		DL	PEMA	73	HL
87190	REPL SPRINK SYS	152178	10604	7.7	SPEC		DL	OMA	72	HL
87190	DRAINAGE WK BDG & EM	14400	11200	86.4	ORIG		DL	MCA	66	HL
87190	DIKE FOR AB GR ST TK	74000	21493	32.3	SPEC		DL	MCA	72	HL
87210	ERECT FENCE	113903	3815	3.7	ORIG		DL	MCA	72	HL
88096	WPC MONITOR STATION	130000	16492	14.1	ORIG		DL	MCA	73	HL
89900	SANITARY SEWAGE MAIN	66000	9335	15.7	ORIG		DL	MCAF	74	HL
89900	SEWAGE TRMT & DISPO	675000	37142	6.1	ORIG		DL	MCAF	73	HL

Figure 24. Header data for all 70 projects.

of scope, the fractional amount of design time consumed by each activity, and the fractional amount of design funds consumed by each activity. (An activity is a functional organization performing work during a design phase.) Of the 70 projects, 54 are three-phase, 14 are second- and third-phase only, one is first- and third-phase only, and one is third-phase only. Regressions were made for the 54 and 14 sets of projects. Because of small sample sizes and the fact that many projects were designed to dollar limits, rather than the more conventional unit of measure prescribed by AR 415-28, design time-scope regressions were made only for 15 buildings and five airfield pavement projects.

Regression Results

Tables 13 through 17 summarize results for the five principal sets of regression: all 70; 54 three-phase; 14 two-phase; 15 building; and five airfield pavement projects. The tabulated percentage design times were developed by dividing the mean activity design times by the mean total design time. The tabulated percentage design costs are the mean activity design costs divided by the mean total design cost. Thus, for example, in Table 13, the Estimating Section mean final design phase time is .0599 x 198.25 days = 11.9 days. Similarly, the corresponding Estimating Section mean final design phase cost is .0295 x $38,902 = $1148. The total design time corresponding to a design cost of $38,902 is $-.13230 \times 10^{7}(38902)^2 + .61501 \times 10^{-2}(38902) + 11.75$ days = 231.0 days. The relation of the 198.25 days and 231.0 days figures are as follows: whereas the arithmetic mean of the 70-project total design times is 198.25 days, and the arithmetic mean of the 70-project total design costs is $38,902, the total design time in terms of the arithmetic mean total design cost, as determined by a formula which is a best fit to all 70 projects, is 231 days. The computed multiple correlation coefficient--R = .94--for this formula indicates a strong relationship between design time, total design cost squared, and total design cost. R^2 = .88 is a measure of the total design time variation (88 percent) explained by the relationship.* The corresponding R^2 values for the other four principal sets of regressions ranged from .83 to .91.

Table 18 indicates the typically encountered dispersion of data and correlation of variables. The mean percent design times and costs and the mean percent standard deviations of design times and costs are to be used with the Table 14 mean total design time and mean total design cost--213.16 days and $42,720, respectively. Thus, the Estimating Section mean final design phase time is .058 (from Table 18) x 213.6 days (from Table 14) = 12.4 days, with a standard deviation of .061 (Table 18) x 123.16 days = 13.0 days (Table 14) for the 54 three-phase projects. Similarly, the Estimating Section mean final design

*When the correlation between two variables exceeds .95, one may be quite accurately estimated from the other. In the range .75 to .85, one may be roughly estimated from the other. When the correlation coefficient is less than .35, there is little association.

Table 13

Percentage Design Times and Costs, All 70 Projects

TIME CALCULATIONS	All Phases	Preliminary Phase	Advanced Final Phase	Final Phase
Design Branch Sections	100.00	25.63	48.00	26.37
Architectural	8.49	2.49	3.91	2.09
Civil	17.28	4.67	8.27	4.34
Electrical	16.07	4.38	8.12	3.57
Estimating	15.59	4.09	5.51	5.99
Mechanical	11.70	3.60	5.70	2.40
Specifications	9.93	.41	6.25	3.27
Structural	11.79	3.35	5.99	2.45
Drafting	9.15	2.64	4.25	2.26
COST CALCULATIONS				
Branches, Overhead, Other	100.00			
Design Branch	62.10			
Foundations & Materials	4.73			
Survey Branch	3.76			
Project Management Br	6.92			
Overhead	13.98			
Contract	.02			
Other	8.49			
Design Branch Sections	62.10	15.03	33.54	13.53
(Branch Staff)	6.40	1.75	3.52	1.13
Architectural	7.97	2.48	3.91	1.58
Civil	6.79	2.02	3.36	1.41
Electrical	7.99	2.21	4.52	1.26
Estimating	6.75	1.50	2.30	2.95
Mechanical	6.05	1.79	3.22	1.04
Specifications	6.66	.11	4.80	1.75
Structural	6.13	1.48	3.50	1.15
Drafting	7.36	1.69	4.41	1.26

Mean Total Design Time = 198.25 working days

Mean Total Design Cost = $38,902

Total Design Time $= -.13230 \times 10^{-7}$ (Total Design Cost)^2 $+ .61501 \times 10^{-2}$ (Total Design Cost) + 11.75 working days

Table 14

Percentage Design Times and Costs, 54 Three-Phase Projects

TIME CALCULATIONS	All Phases	Preliminary Phase	Advanced Final Phase	Final Phase
Design Branch Sections	100.00	30.32	45.83	23.85
Architectural	8.65	2.91	4.01	1.73
Civil	17.52	5.54	7.87	4.11
Electrical	15.84	5.22	7.42	3.20
Estimating	15.53	4.78	4.90	5.85
Mechanical	11.34	4.23	5.06	2.05
Specifications	9.50	.50	6.04	2.96
Structural	12.11	3.97	6.02	2.12
Drafting	9.51	3.17	4.51	1.83

COST CALCULATIONS	All Phases	Preliminary Phase	Advanced Final Phase	Final Phase
Branches, Overhead, Other	100.00			
Design Branch	63.34			
Foundations & Materials	4.18			
Survey Branch	3.24			
Project Management Br	7.00			
Overhead	14.14			
Contract	.02			
Other	8.08			
Design Branch Sections	63.34	17.37	34.40	11.57
(Branch Staff)	7.05	2.04	3.86	1.15
Architectural	8.35	2.87	4.42	1.06
Civil	6.63	2.29	3.20	1.14
Electrical	7.98	2.58	4.42	.98
Estimating	7.02	1.72	2.31	2.99
Mechanical	5.97	2.04	3.07	.86
Specifications	6.44	.12	4.89	1.43
Structural	6.24	1.72	3.66	.86
Drafting	7.66	1.99	4.57	1.10

Mean Total Design Time = 213.16 working days

Mean Total Design Cost = \$42,720

Total Design Time = $-.13639 \times 10^{-7}$ (Total Design Cost)^2 + .62664 $\times 10^{-2}$ (Total Design Cost) + 11.85 working days

Table 15

Percentage Design Times and Costs, 14 Two-Phase Projects

TIME CALCULATIONS	All Phases	Preliminary Phase	Advanced Final Phase	Final Phase
Design Branch Sections	100.00	0	69.63	30.37
Architectural	4.90	0	4.06	.84
Civil	17.23	0	12.15	5.08
Electrical	17.99	0	13.71	4.28
Estimating	16.67	0	10.07	6.60
Mechanical	13.82	0	10.49	3.33
Specifications	12.66	0	8.65	4.01
Structural	8.94	0	6.95	1.99
Drafting	7.79	0	3.55	4.24
COST CALCULATIONS				
Branches, Overhead, Other	100.00			
Design Branch	52.60			
Foundations & Materials	8.42			
Survey Branch	6.95			
Project Management Br	7.22			
Overhead	13.57			
Contract	.03			
Other	11.21			
Design Branch Sections	52.60	0	36.87	15.73
(Branch Staff)	3.26	0	2.06	1.20
Architectural	1.84	0	1.37	.47
Civil	8.17	0	5.50	2.67
Electrical	8.90	0	6.49	2.41
Estimating	5.65	0	2.85	2.80
Mechanical	6.47	0	5.21	1.26
Specifications	8.10	0	5.54	2.56
Structural	4.36	0	3.32	1.04
Drafting	5.85	0	4.53	1.32

Mean Total Design Time = 142.15 working days

Mean Total Design Cost = $23,228

Total Design Time = $.51960 \times 10^{-2}$ (Total Design Cost) + 21.45 working days

Table 16

Percentage Design Times and Costs, 15 Building Projects

TIME CALCULATIONS	All Phases	Preliminary Phase	Advanced Final Phase	Final Phase
Design Branch Sections	100.00	31.57	43.08	25.35
Architectural	14.91	4.17	6.73	4.01
Civil	12.67	4.40	4.88	3.39
Electrical	11.75	3.31	5.72	2.72
Estimating	16.04	5.74	4.68	5.62
Mechanical	14.79	5.58	6.38	2.83
Specifications	7.13	.00	4.82	2.31
Structural	13.79	4.50	6.44	2.85
Drafting	8.92	3.87	3.43	1.62
COST CALCULATIONS				
Branches, Overhead, Other	100.00			
Design Branch	65.91			
Foundations & Materials	3.12			
Survey Branch	1.78			
Project Management Br	6.35			
Overhead	14.14			
Contract	.00			
Other	8.70			
Design Branch Sections	65.91	18.15	34.54	13.22
(Branch Staff)	8.54	2.36	4.98	1.20
Architectural	12.87	3.87	6.32	2.68
Civil	4.55	1.68	1.87	1.00
Electrical	6.27	2.09	3.25	.93
Estimating	6.87	1.87	2.39	2.61
Mechanical	7.38	2.73	3.36	1.29
Specifications	5.64	.00	4.33	1.31
Structural	7.55	1.90	4.41	1.24
Drafting	6.24	1.65	3.63	.96

Mean Total Design Time = 379.32 working days

Mean Total Design Cost = \$92,722   Mean Scope = 63,199 square feet

Total Design Time $= -.14918 \times 10^{-7}(\text{Total Design Cost})^2 + .68802 \times 10^{-2}(\text{Total Design Cost}) - 47.25$ working days

$= -.13114 \times 10^{-7}(\text{Scope})^2 + .56363 \times 10^{-2}(\text{Scope}) + 188.70$ working days

Table 17

Percentage Design Times and Costs, Five Airfield Paving Projects

TIME CALCULATIONS	All Phases	Preliminary Phase	Advanced Final Phase	Final Phase
Design Branch Sections	100.00	17.59	61.91	20.50
Architectural	2.05	1.21	.61	.23
Civil	32.88	7.05	20.75	5.08
Electrical	26.60	4.15	17.91	4.54
Estimating	14.93	2.96	6.62	5.35
Mechanical	3.14	1.56	1.19	.39
Specifications	7.43	.00	5.62	1.81
Structural	7.22	.53	4.97	1.72
Drafting	5.75	.13	4.24	1.38
COST CALCULATIONS				
Branches, Overhead, Other	100.00			
Design Branch	53.83			
Foundations & Materials	10.30			
Survey Branch	7.92			
Project Management Br	4.84			
Overhead	14.86			
Contract	.05			
Other	8.20			
Design Branch Sections	53.83	7.87	36.34	9.62
(Branch Staff)	3.15	.82	1.54	.79
Architectural	.96	.61	.25	.10
Civil	14.17	4.03	8.50	1.64
Electrical	13.92	.98	11.06	1.88
Estimating	4.88	.66	2.38	1.84
Mechanical	.95	.52	.28	.15
Specifications	5.57	.00	4.20	1.37
Structural	2.88	.12	2.09	.67
Drafting	7.35	.13	6.04	1.18

Mean Total Design Time = 211.68 working days

Mean Total Design Cost = $46,251   Mean Scope = 44,286 square yards

Total Design Time $= -4.0829 \times 10^{-7}(\text{Total Design Cost})^2 + .85089 \times 10^{-2}(\text{Total Design Cost}) - 43.68$ working days

$= -.34446 \times 10^{-7}(\text{Scope})^2 + .73891 \times 10^{-2}(\text{Scope}) + 32.85$ working days

Table 18

Mean Percent Design Times and Costs (μ), Standard Deviations (σ), and Correlation Coefficients (ρ), 54 Three-Phase Projects

	All Phases			Preliminary Phase			Adv Final Phase			Final Phase		
TIME CALCULATIONS	μ	σ	ρ	μ	σ	ρ	μ	σ	ρ	μ	σ	ρ
Design Branch Sections	100.0	91.3		30.3	34.2	.94	45.8	40.8	.93	23.9	23.5	.89
Architectural	8.7	16.6	.82	2.9	5.4	.80	4.0	8.4	.72	2.8	3.8	.82
Civil	17.5	17.6	.70	5.5	5.7	.71	7.9	9.3	.65	4.1	5.0	.60
Electrical	15.8	21.2	.70	5.2	8.2	.56	7.4	10.0	.67	3.2	7.3	.71
Estimating	15.5	15.6	.83	4.8	7.2	.77	4.9	4.4	.80	5.8	6.1	.80
Mechanical	11.4	15.0	.73	4.2	6.4	.79	5.1	7.1	.71	2.1	3.1	.57
Specifications	9.5	8.0	.68	.5	1.8	-.04	6.0	5.2	.71	3.0	3.0	.68
Structural	12.1	15.2	.77	4.0	6.2	.76	6.0	7.7	.74	2.1	2.8	.62
Drafting	9.5	13.9	.68	3.2	9.4	.65	4.5	7.2	.56	1.8	2.6	.71
COST CALCULATIONS												
Branches, Overhead, Other	100.0	130.3										
Design Branch	63.3	86.4	.98									
Foundations & Materials Br	4.3	6.3	.45									
Survey Branch	3.2	4.7	.32									
Project Management Br	7.0	8.1	.89									
Overhead	14.1	23.5	.90									
Contract	.0	.1	.12									
Other	8.1	13.9	.94									
Design Branch Sections	63.3	86.4		17.3	25.0	.92	34.4	51.1	.97	11.6	15.1	.92
(Branch Staff)	7.0	25.4	.76	2.0	6.3	.69	3.9	16.6	.77	1.1	2.7	.74
Architectural	8.4	18.7	.89	2.9	5.6	.85	4.4	11.8	.89	1.1	2.2	.84
Civil	6.6	8.2	.66	2.3	2.9	.60	3.2	4.5	.56	1.1	1.5	.75
Electrical	8.0	10.9	.65	2.6	4.5	.68	4.4	6.6	.61	1.0	1.4	.86
Estimating	7.0	10.9	.91	1.7	3.0	.89	2.3	3.6	.90	3.0	5.2	.92
Mechanical	6.0	9.9	.64	2.0	4.4	.68	3.1	5.8	.61	.9	1.4	.53
Specifications	6.4	7.0	.80	.1	.5	-.10	4.9	6.0	.75	1.4	1.6	.75
Structural	6.2	11.5	.66	1.7	4.1	.69	3.6	7.8	.61	.9	1.2	.66
Drafting	7.7	10.2	.83	2.0	3.9	.69	4.6	6.0	.89	1.1	1.9	.77

Note: The arrows are located at a variable which is correlated with the string of variables in the direction of the arrow.

phase cost is .030 x \$42,720 = \$1282, with a standard deviation of 0.52 x \$42,720 = \$2221. The correlation of Estimating Section final design phase time with Design Branch final design phase time is .80. In turn, the correlation of Design Branch final design phase time with total design time is .89. The correlation of Estimating Section final design time is .89. The correlation of Estimating Section final design phase cost with Design Branch design phase cost is .92. In turn, the correlation of Design Branch final design phase cost with total design cost is .92. As would be expected, the percent cost standard deviations are somewhat greater than the percent design time standard deviations. Time data have less dispersion because there are practical upper and lower limits to design time. Certainly, if a large job costs 10 times as much as a small one, there is an inclination to put more men on the job and not take 10 times as long. The large cost standard deviations indicate only that there was a mixture of jobs of different total cost (the largest was \$320,555; the smallest was \$3815). The important factor is whether the deviation can be accounted for by regression; the correlation coefficient is a measure of whether the dispersion can be explained by regression. There are only three poor correlation coefficients in the table--those for Foundations and Materials Branch cost, Survey Branch cost, and contract cost. The contract cost correlation coefficient can be ignored, since these projects were designed in-house, and therefore there was virtually no contract cost.

Table 19 presents design section relative times and costs as a percentage of total branch time and cost. It would be expected that Estimating Section mean final design phase cost--5.31 percent of Design Branch (less branch staff) mean total design cost--should be approximately the same as the Estimating Section mean final design phase time--5.85 percent of Design Branch mean total design time. Differences in corresponding percentage values are attributable to sectional average manhour costs and crew size, since (manhour cost) (8 hours/day) (crew size) (section fractional design time) (total design working days) = design cost = (design section fractional design cost) (design branch fractional design cost - design branch staff fractional design cost) (total design cost), all in consistent dimensions. In the case of Estimating Section mean final design phase cost, (10.37)(8)(1.2)(.0585) (213.16) = \$1241 ≈ (.0531)(.6334 - .0705) (42,720) = \$1277. The \$1241 and \$1277 values are reasonably close and the difference is due to loss of significant places in the coefficients used, especially crew size. The average sectional manhour cost, \$9.04, is the sum of the products of individual sectional manhour costs and crew size, divided by the sum of the sectional crew sizes. Thus, the crude average sectional crew size is (design branch fractional design time - design branch staff fractional design time) (mean total design cost)/[(mean total design working days) (8 hours/day) (mean manhour cost)] = (.6334 - .0705) (42,720)/ [2.3.16(8)(9.04)] = 1.56 men. Overall, the average number of men employed on the project, excluding overhead and other costs, is (1 - .1414 - .0808) (42,720)/[213.16(8)(9.04)] = 1.99 men, although the \$9.04 manhour rate is not strictly applicable to Foundations and Materials, Survey, and Project Management Branches. In summary, it takes a commitment of two men for every project in progress.

Table 19

Design Branch Relative Times and Costs, 54 Three-Phase Projects

	All Phases	Preliminary Phases	Advanced Final Phase	Final Phase
Sectional Times	100.00	30.32	45.83	23.85
Architectural	8.65	2.91	4.01	1.73
Civil	17.52	5.54	7.87	4.11
Electrical	15.84	5.22	7.42	3.20
Estimating	15.53	4.78	4.90	5.85
Mechanical	11.34	4.23	5.06	2.05
Specifications	9.50	.50	6.04	2.96
Structural	12.11	3.97	6.02	2.12
Drafting	9.51	3.17	4.51	1.83
Sectional Costs	100.00	27.23	54.25	18.52
Architectural	14.83	5.08	7.86	1.89
Civil	11.78	4.07	5.68	2.03
Electrical	14.18	4.59	7.85	1.74
Estimating	12.47	3.06	4.10	5.31
Mechanical	10.60	3.62	5.46	1.52
Specifications	11.44	.22	8.67	2.55
Structural	11.09	3.05	6.51	1.53
Drafting	13.61	3.54	8.12	1.95
Sectional Hourly Costs	9.04			
Architectural	11.34			
Civil	10.12			
Electrical	11.26			
Estimating	10.37			
Mechanical	11.46			
Specifications	8.10			
Structural	10.48			
Drafting	5.61			
Sectional Crew Size	13.3	11.1	15.6	10.1
Architectural	2.1	2.2	2.4	1.4
Civil	.9	1.2	1.0	.7
Electrical	1.1	1.1	1.3	.7
Estimating	1.1	.9	1.1	1.2
Mechanical	1.2	1.1	1.3	.9
Specifications	2.1	.8	2.5	1.5
Structural	1.2	1.0	1.5	1.0
Drafting	3.6	2.8	4.5	2.7

Use of Results

The detailed analysis of the Fort Worth data can be used to estimate the labor impact on District forces of a new design job. For example, if the work requirements of a $100,000 (design cost) three-phase project were desired, the total design time could be estimated from the regression-derived equation of Table 14 or from the graph in Figure 25. The total design time (503 days) could be distributed to the various design sections and phases by the percentage figures in Table 19.

The reader should not try to infer too much from the data presented in this section. The sample sizes are small, and the effects of different facility classes and construction categories cannot be sorted with any precision. Applying the results to the operations of a District other than Fort Worth may not be proper. Some types of funds or programs are not well represented, and family housing is not represented at all. Inferring design time for work done under contract may not be applicable. All the construction for these projects may be considered to be permanent. Furthermore, it is not possible to make distinctions among original designs, site adaptations of standard or prior designs, or designs for alterations and/or additions. In addition, it should not be inferred that all types of statistical analysis have been exhausted.

What can be concluded is that data of this type, which would be conventionally available for completed projects controlled under activity network analysis procedures, can be evaluated by multiple regression analysis to yield information useful for estimating project design time, activity design time, and activity design cost for future work.

ER 451-345-43 Progress Reporting Data

There are data for 7433 completed Corps construction projects in the form specified in ER 415-345-43, Military Design and Construction Progress Reporting. Records presently exist for projects from 1967 to 1974. Figure 26 gives a format for the master file used for regression analysis of these data. The data basically contain time and cost information related to design and construction.

Table 20 provides a comparison of the general MIDAS data and detailed Fort Worth data. Of the 285 projects investigated in the preceding sections, 79 were District Engineer designed. The overlap of the two data bases is minimal, perhaps 10 percent. Two years separate the two sets of data; earlier inactive projects have been dropped from the Fort Worth data base. Since this section contains data only on preliminary, advanced final, and final design, 54 Fort Worth projects having all three design periods were selected from the 285 projects. Costs were converted to FY 74 by a factor of 162.5/134.5 (Table 8). A weighted average project design cost of $50,210 is used for the 79 projects of the preceding sections: 33 preliminary projects at $62,072;

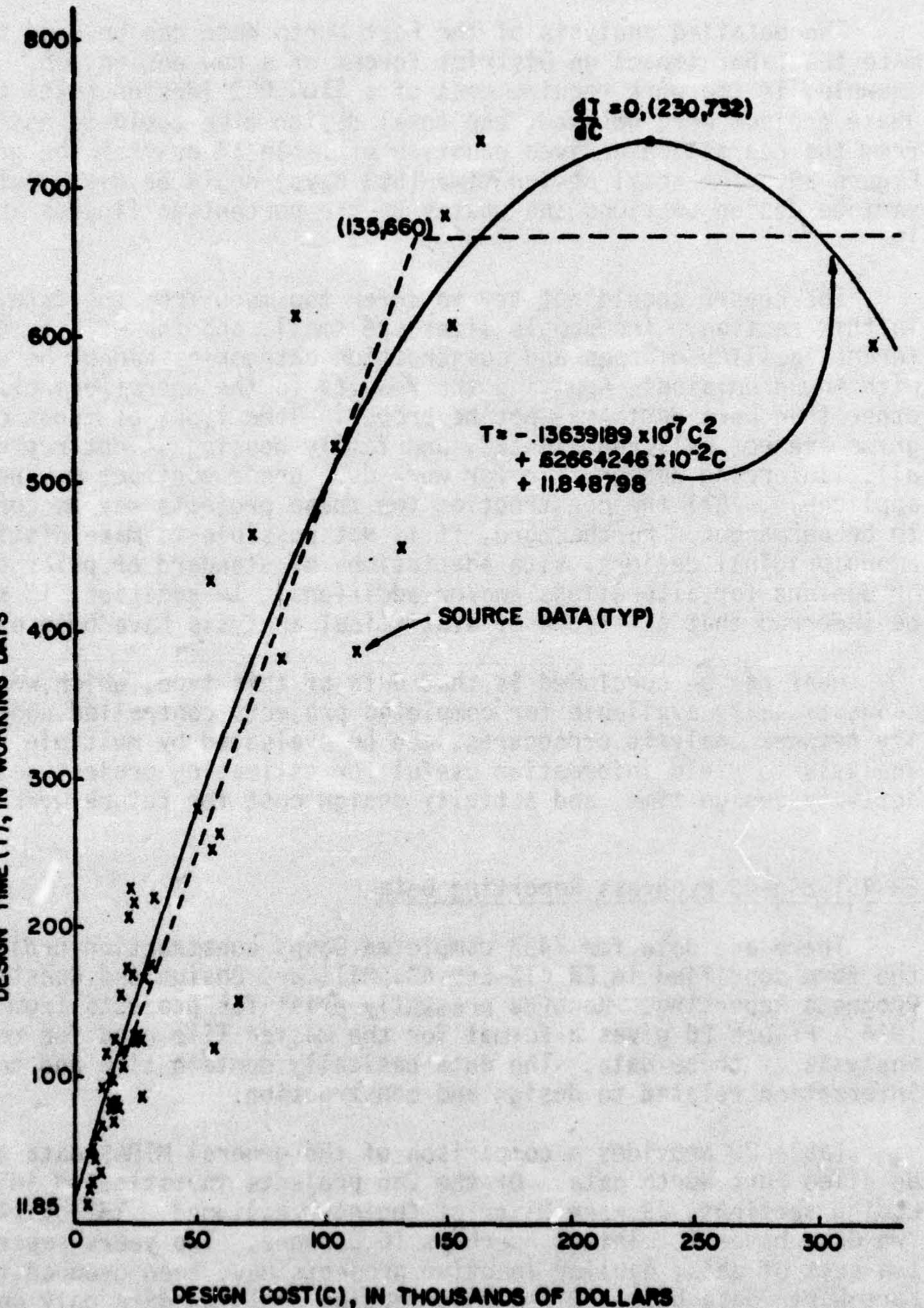


Figure 25. Design time-cost relation, 54 three-phase projects.

Field	Information	Accepted Format	Special Editing Checks and Adjustments
1-3	Station name	Alphanumeric or blank	
4-9	Scope	Integer field, right justified	Must be positive integer
10-11	Unit of measure	Alphanumeric	Only units of SF, SY, MN, MM, MF, FM are acceptable
12-18	Category code	Integer field, right or left justified	Must be positive
19-22	A/E cost	Integer or zeros*	Adjust all cost items to same base year of 1974
23-26	A/E superseded or deleted	Integer or blank (non-negative integer)	Adjust all cost items to same base year of 1974
27-30	D/E cost	Integer or blank (non-negative)	Adjust all cost items to same base year of 1974
31-34	D/E superseded or deleted	Integer or blank* (non-negative integer)	Adjust all cost items to same base year of 1974
35-38	Total design cost°	Integer or blank (non-negative)	Adjust all cost items to same base year of 1974
39-42	Design start date	Positive integer+	Must be earlier than all other design and construction dates
43-46	Original scheduled completion date	Positive integer+	
47-50	Expected design completion date	Positive integer+	
51-54	Construction start date	Positive integer+	Must be earlier than all other construction dates
55-60	Construction total direct cost	Positive integer (nonzero, non-negative)	Adjust cost items to a base year of 1974
61-64	Total E&D Cost	Integer or blank+ (non-negative)	Adjust cost items to a base year of 1974
65-68	Original construction scheduled completion date	Integer or blank+ (non-negative)	
69-72	Expected construction completion date	Integer or blank (non-negative)	

* Both A/E and D/E cost cannot be zero concurrently.
° Total design cost = A/E cost + A/E superseded + D/E cost + D/E superseded.
+ All time data must take values between 0 and 2555.

Figure 26. Master file used for regression analysis of ER 415-345-43 data.

Table 20

Comparison of 79 MIDAS and 54 Detailed Projects Data
District Engineer Designs

Project Data Items	79 Projects	54 Projects
Mean Design Time, Calendar Days		
Preliminary	122	94
Advanced or Early Final	111	141
Final	84	74
Total	317	309
Mean Fractional Time, Percentage		
Preliminary	38	30
Advanced or Early Final	35	46
Final	27	24
Total	100	100
Design Time Standard Deviation		
Preliminary	57	106
Advanced or Early Final	76	126
Final	94	73
Total	--	282
Ratio of Standard Deviation to Mean Time		
Preliminary	.49	1.13
Advanced on Early Final	.69	.89
Final	1.12	.99
Total	--	.91
Design Time-Cost Correlation Coefficient	.66	.94
Total Design Cost		
Maximum Project, Dollars	203,547	320,555
Minimum Project, Dollars	3,611	3,815
Mean of all Projects, Dollars	50,210	51,613
Standard Deviation, Dollars	42,258	67,268
Ratio of Standard Deviation to Mean	.90	1.30
Expenditure Rate, Dollars/Calendar Day		
Maximum	1,097	449
Minimum	60	80
Mean	158	167
Mean Project Crew Size, Men (Direct Labor)		
Maximum	10.2	4.2
Minimum	.6	.7
Mean	1.5	1.6

73 advanced final projects at $42,602; and 34 final projects at $55,031. The weighted average standard deviation design cost was computed similarly. Correlation coefficients of these two sections cannot be matched well. Table 20 shows that results of the two sections are reasonably consistent and very close on overall mean design time, mean total design cost, and mean crew size.

ER 415-345-43 data were analyzed in this study to develop a gross prediction of the overall required design time as a function of project type and scope.

Procedure

Projects within the same category code were initially sorted from the master tape, and were then grouped according to project size and type. Detailed analyses were made on projects of the following groups:

Category Code	Description
100--	Operational Facilities
171--	Training Facilities
211--	Aircraft Maintenance
212--, 215--, 216--, 217--	Weapons Repair
214--	Automotive Vehicle Repair
218--, 219--	Miscellaneous Maintenance Facilities
510--	Hospital Buildings
610--	Administrative Buildings
711--	Family Housing
722--	Troop Housing - Enlisted Mens Barracks Without Mess
800--	Utilities

The following variables were used to analyze hospital, training facility, and administrative buildings data:

Scope (sq ft)

Total A/E cost (contracted)

Total DE cost (in-house)

Total design cost

Percent engineering to construction

Design state date

Original scheduled completion date (design)

Expected completion date (design)

Construction contract award date

Total direct construction cost

Engineering and design cost

Original scheduled completion date (construction)

Expected completion date (construction)

In addition, for the remainder of the projects, the same variables were used without percent engineering to construction, plus A/E superseded and deleted costs and DE superseded and deleted costs.

Many of the projects which were initially retrieved were not usable due to inconsistencies and errors in the data entries. These records were eliminated from consideration. All dates were converted to calendar days starting from 1 January 1968. Variables were computed from the scheduled dates to represent time durations. All monetary entries were updated to 1974 dollars, using conversion factors obtained from the November 1974 issue of the Department of Commerce's *Construction Review*. The conversion factors used were:

From	To	Conversion Factor
1968	1974	180/107
1969	1974	180/114
1970	1974	180/121
1971	1974	180/130
1972	1974	180/139
1973	1974	180/152

Regression Criteria

Regressions were run on groups of data having scope in homogeneous units of measure within each category code. In several of the project categories, scope had to be converted to square feet. For enlisted men's barracks without mess, a figure of 127.5 sq ft (11.9 m^2) per

person was determined to be the average area allowance. This includes central areas such as hallways and lounge areas.

A problem arose in this category code concerning the scope's unit of measure. Despite the standard set in AR 415-15 (DOD Construction Criteria), which states that MN (persons) should be used as the unit of measure for buildings such as barracks, units of measure such as EW, MM, WO, and EM were observed. This made editing by computer difficult. For the family housing data, units of measure such as UN (units), EA (each), and FA (family) were observed, thus making conversions to a suitable uniform unit of measure difficult. The type of housing (for example, NCO or officer) can be determined from the category code. Average square footage for the different types of housing was determined from a housing project at Fort Bragg, NC. The conversion factors used were:

Housing Type	Sq Ft/Unit
NCO	1100
GS 12-14	1400
Major, Lieutenant Colonel	1670
Colonel, General	2100
Other (category codes 71100, 71190)	1100

It is difficult to arrive at a homogeneous unit of measure for scope for the family housing data because the given units were so vague. One "UN" might represent a single family dwelling or a duplex, either of which could have two, three, or four bedrooms per family. The family housing regression results involving scope, therefore, may not be reliable.

Furthermore, project editing was done by inspection. Total design cost must equal the sum of: (1) A/E cost; (2) A/E superseded or deleted; (3) DE cost; and (4) superseded or deleted. Both A/E and DE costs must not be concurrently equal to zero. The total direct construction cost must be greater than zero (in actuality, the construction cost was compared to the design cost and if it was unreasonably small, the project was assumed to have been terminated prior to completion and was, therefore, eliminated from consideration). Edit checks on dates consisted mostly of checking for unreasonable results; for example, if a starting date is earlier than a completion date. Projects violating the above criteria were rejected from the analysis.

Linear regressions were performed for selected dependent variables against the associated independent variables in a stepwise fashion (Figure 27). A series of polynomial regressions was also performed

Dependent Variables	Independent Variables
Expected Design Time (T)	Scope (A) Construction Total Direct Cost (M) Total A/E Cost (AET) Total D/E Cost (DET) Total Design Cost (G) Originally Scheduled Design Time (X)
Design Time Overrun (V)	Scope (A) Construction Total Direct Cost (M) Total A/E Cost (AET) Total D/E Cost (DET) Total Design Cost (G) Originally Scheduled Design Time (X)
A/E Cost (B)	Scope (A) Construction Total Direct Cost (M) Expected Design Time (T) Originally Scheduled Design Time (X)
A/E Superseded or Deleted (C)	Scope (A) Construction Total Direct Cost (M) Expected Design Time (T) Originally Scheduled Design Time (X)
D/E Cost (D)	Scope (A) Construction Total Direct Cost (M) Expected Design Time (T) Originally Scheduled Design Time (X)
D/E Superseded or Deleted (F)	Scope (A) Construction Total Direct Cost (M) Expected Design Time (T) Originally Scheduled Design Time (X)
Total A/E Cost (AET)	Scope (A) Construction Total Direct Cost (M) Total Design Cost (G) Expected Design Time (T) Originally Scheduled Design Time (X)
Total D/E Cost (DET)	Scope (A) Construction Total Direct Cost (M) Expected Design Time (T) Originally Scheduled Design Time (X)
Ratio of E&D Cost to Design Cost (EDR) (= P/G)	Scope (A) Construction Total Direct Cost (M) Expected Design Time (T) Originally Scheduled Design Time (X)

Figure 27. Regression analysis of ER 415-345-43 data.

for the dependent variables against all independent variables individually. Elapsed time was computed for design time, originally scheduled design time, design time overrun, construction time, originally scheduled construction time, and construction time overrun. These variables were measured in days.

Projects within each category code were placed in two groups: in-house projects, where the work was actually done by the District, and contracted projects, where the work was contracted to a civilian A/E firm.

In cases where the number of records was large, regressions were run on the group as a whole as well as by division to determine if the same relationships were uniform for all divisions or if they varied by division.

Derived Variables

Before analyzing the different relationships, a set of derived data was established.

a. T (Expected Design Time) = K (Expected Design Completion Date) - H (Design Start Date)

b. V (Design Time Overrun) = K (Expected Design Completion Date) - J (Originally Scheduled Completion Date)

c. X (Originally Scheduled Design Time) = J (Originally Scheduled Completion Date) - H (Design Start Date)

d. Y (Expected Construction Time) = S (Expected Construction Completion Date) - L (Construction Start Date)

e. W (Construction Time Overrun) = S (Expected Construction Completion Date) - R (Originally Scheduled Construction Completion Date)

f. Z (Originally Scheduled Construction Time) = R (Originally Scheduled Construction Completion Date) - L (Construction Start Date)

g. AET (Total A/E Cost) = B (A/E Cost) + C (A/E Superseded or Deleted)

h. DET (Total DE Cost) = D (DE Cost) + F (DE Superseded or Deleted)

i. EDR (Ratio of E&D Cost to Design Cost) = P (Total E&D Cost)/ G (Total Design Cost)

Regression Results--Linear Regressions

Figures 28 through 42 give results of the stepwise linear regressions. An "x" indicates that the independent variables were entered at the 90 percent or higher confidence level. If the α* for the constant is not given, it is less than or equal to 0.1.

Regression Results--Polynomial Regressions

Quadric and cubic equations were fitted stepwise to contracted family housing and EM barracks data. Figures 43 through 46 give the results.

Conclusions From Analysis

Independent design time estimating equations were developed for both in-house and A/E projects for a variety of category codes. Where sample sizes were large, separate analyses were performed by District. The only consistently observed independent variable related to expected design time was the originally scheduled design time. It was hoped that a consistent relationship (in the sense of a correlation) would be observed between expected design time and some project descriptor that would be available prior to design initiation. Some relations of this type were observed, but they were exceptions.

Results of Overall Data Analysis

Anticipated Goal

It was anticipated that the combination of the prior analyses would estimate a new project's impact on the in-house design labor force. This was to be accomplished by:

a. Estimating total design time by analyzing ER 415-345-43 data

b. Estimating the distribution of total design time into project design phase times by evaluating 285 Fort Worth MIDAS projects

c. Developing section-level active design time requirements by phase by evaluating the detailed records of 70 Fort Worth projects.

Actual Results

Two of these goals (b and c above) were accomplished, although accuracy of the numbers is not as precise as would be desirable.

Evaluating the general distribution of design time into phases revealed that the largest single portion of the design process is

---

* α is error of the first kind; the probability of rejecting the relationship when in fact it is correct.

Dependent Variable T	A	M	AET	DET	G	X	Remarks
			Independent Variables				
EM Barracks (All)		x			x	x	
EM Barracks (SPD)				x	x		With x, constant's α = .202
EM Barracks (MRD)						x	Constant's α = .202
EM Barracks (POD)						x	
EM Barracks (SAD)						x	
EM Barracks (SWD)						x	Constant's α = .187
EM Barracks (NAD)						x	
Family Housing (All)	x					x	
Family Housing (NAD)			x			x	
Family Housing (SWD)			X and T have correlation coefficient = 1.0				
Family Housing (SAD)						x	Constant's α = .615
Supply (Sq. Ft.)						x	Constant's α = .267
Operational Buildings						x	
Supply (BL)						x	Constant's α = .131
Weapons Repair						x	Constant's α = .851
Aircraft Maintenance	x			x		x	Constant's α = .399 (M enters at 88%)
Maintenance (Missile)	x	x	x			x	
Automotive Maintenance				x		x	Constant's α = .605
Maintenance Facilities						x	Constant's α = .602
Administrative Buildings		x		x	x	x	Constant's α = .511
Hospital						No Regressions	
Training Facility (All)						x	
Training Facility (MRD)						x	
Training Facility (SAD)					No Regressions		
Training Facility (SPD)					No Regressions		
Training Facility (SWD)					No Regressions		
Training Facility (NAD)						x	Constant's α = .233

Figure 28. Linear regression analysis of ER 415-345-43 data: expected design time vs. independent variable for contracted work.

Dependent Variable V	A	M	AET	DET	G	X	Remarks
	Independent Variables						
EM Barracks (All)		x			x	x	
EM Barracks (SPD)		x		x	x		
EM Barracks (MRD)							No variables entered
EM Barracks (POD)							No variables entered
EM Barracks (SAD)						x	
EM Barracks (SWD)						x	Constant's α = .187
EM Barracks (NAD)							No variables entered
Family Housing (All)	x					x	
Family Housing (NAD)	x					x	
Family Housing (SWD)					V = 0		
Family Housing (SAD)							No variables entered
Supply (Sq. Ft.)							No variables entered
Operational Buildings							No variables entered
Supply (BL)						x	Constant's α = .131
Weapons Repair							No variables entered
Aircraft Maintenance	x	x	x	x			Constant's α = .979
Maintenance (Missile)	x	x			x		
Automotive Maintenance				x			Constant's α = .310
Maintenance Facilities							No variables entered
Administrative Buildings		x		x	x	x	Constant's α = .5
Hospital				No	Regressions		
Training Facility						x	
Training Facility (MRD)						x	
Training Facility (SPD)					V = 0		
Training Facility (SWD)					V = 0		
Training Facility (SAD)					V = 0		
Training Facility (NAD)							No variables entered

Figure 29. Linear regression analysis of ER 415-345-43 data: design time overrun vs. independent variable for contracted work.

	Independent Variables					
Dependent Variable T	A	M	DET	G	X	Remarks
EM Barracks (All)					x	
EM Barracks (NAD)					x	Constant's α = .169
EM Barracks (POD)					x	Constant's α = .989
EM Barracks (SAD)					x	Constant's α = .246
EM Barracks (SPD)					x	Constant's α = .872
EM Barracks (SWD)					x	Constant's α = .914
Family Housing					x	Constant's α = .265
Operations Buildings					x	Constant's α = .778
Weapons Repair					x	Constant's α = .756
Maintenance (Missile)					x	Constant's α = 1.0
Automotive Vehicle Maintenance					x	Constant's α = .557
Training Facilities				No Regressions		
Training Facilities (SPD)				No Regressions		
Training Facilities (SAD)				No Regressions		

Figure 30. Linear regression analysis of ER 415-345-43 data: expected design *time* vs. *independent* variable for in-house work.

	Independent Variables					
Dependent Variable V	A	M	DET	G	X	Remarks
EM Barracks (All)						No variables entered
EM Barracks (NAD)		x			x	Constant's α = .76
EM Barracks (POD)						No variables entered
EM Barracks (SAD)						No variables entered
EM Barracks (SPD)						No variables entered
EM Barracks (SWD)						No variables entered
Family Housing						No variables entered
Operations Buildings						No variables entered
Weapons Repair						No variables entered
Maintenance (Missile)				V = 0		
Automotive Vehicle Maintenance						No variables entered
Training Facilities				No Regressions		
Training Facilities (SPD)				No Regressions		
Training Facilities (SAD)				No Regressions		

Figure 31. Linear regression analysis of ER 415-345-43 data: design time overrun vs. independent variable for in-house work.

AD-A035 208 CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAI--ETC F/G 5/1
ENGINEERING AND DESIGN PERFORMANCE ANALYSIS. (U)
DEC 76 R L LAPP, J G KIRBY
UNCLASSIFIED CERL-IR-C-75 NL

2 OF 4
AD
A035208

Dependent Variable B	A	M	T	X	Remarks
	Independent Variables				
EM Barracks (All)	x	x			X entered at 85% conf. level
EM Barracks (SPD)	x	x	x		
EM Barracks (MRD)		x			Constant's α = .397
EM Barracks (POD)		x			
EM Barracks (SAD)	x	x			
EM Barracks (SWD)	x	x			Constant's α = .534
EM Barracks (NAD)	x	x			
Family Housing (All)		x			
Family Housing (NAD)		x			
Family Housing (SWD)			x		Constant's α = .432
Family Housing (SAD)			x		
Supply (Sq. Ft.)		x			Constant's α = .814
Operational Buildings	x	x			
Supply (BL)		x			
Weapons Repair		x			Constant's α = .468
Aircraft Maintenance	x	x	x	x	Constant's α = .242
Maintenance (Missile)	x				Constant's α = .104
Automotive Maintenance					No variables entered (A, T, X entered at 88% conf. level)
Maintenance Facilities		x			Constant's α = .823
Training Facilities		x			Constant's α = .263

Figure 32. Linear regression analysis of ER 415-345-43 data: A/E cost vs. independent variable for contracted work.

Dependent Variable	C	A	M	AET	DET	G	X	T	Remarks
				Independent Variables					
EM Barracks (All)			x						
EM Barracks (SPD)		x						x	
EM Barracks (MRD)			x						Constant's α = .818
EM Barracks (POD)									No variables entered
EM Barracks (SAD)							x	x	Constant's α = .4
EM Barracks (SWD)								x	Constant's α = .264
EM Barracks (NAD)									No variables entered
Family Housing (All)			x						Constant's α = .285
Family Housing (NAD)						C	= 0		
Family Housing (SWD)						C	= 0		
Family Housing (SAD)			x						Constant's α = .84
Supply (Sq. Ft.)			x						Constant's α = .524
Operational Buildings								x	
Supply (BL)						C	= 0		
Weapons Repair									No variable entered
Aircraft Maintenance									No variable entered
Maintenance (Missile)									No variable entered
Automotive Maintenance									No variable entered
Maintenance Facilities						C	= 0		

Figure 33. Linear regression analysis of ER 415-345-43 data: A/E superseded or deleted vs. independent variable for contracted work.

Dependent Variable D	A	M	T	X	Remarks
EM Barracks (All)		x			With A, constant's α = .602
EM Barracks (SPD)					
EM Barracks (MRD)		x	x		With T, constant's α = .586
EM Barracks (POD)				x	Constant's α = .679
EM Barracks (SAD)	x		x		Constant's α = .152
EM Barracks (SWD)		x	x		Constant's α = .237
EM Barracks (NAD)	x	x			
Family Housing (All)		x			
Family Housing (NAD)					No variables entered
Family Housing (SWD)		x	x		
Family Housing (SAD)	x		x	x	
Supply (Sq. Ft.)		x			
Operational Buildings	x	x			
Supply (BL)		x			Constant's α = .734
Weapons Repair		x		x	Constant's α = .637
Aircraft Maintenance	x	x	x	x	Constant's α = .982
Maintenance (Missile)	x	x	x	x	Constant's α = .193
Automotive Maintenance		x			Constant's α = .766
Maintenance Facilities					No variable entered
Training Facilities	x				Constant's α = .646
Hospital	x	x			Constant's α = .39
Administrative Buildings	x	x	x	x	Constant's α = .283

Figure 34. Linear regression analysis of ER 415-345-43 data: DE cost vs. independent variable for contracted work.

Dependent Variable D	A	M	T	X	Remarks
Training Facilities (MRD)	x			x	
Training Facilities (SAD)	x	x	x		Constant's α = .375
Training Facilities (SPD)	x	x			
Training Facilities (SWD)	x				
Training Facilities (NAD)	x				

Figure 34. (cont'd)

	Independent Variables				
Dependent Variable D	A	M	T	X	Remarks
EM Barracks (All)		x	x		
EM Barracks (NAD)			x		
EM Barracks (POD)		x			Constant's α = .67
EM Barracks (SAD)		x			Constant's α = .702
EM Barracks (SPD)				x	Constant's α = .696
EM Barracks (SWD)	x	x			Constant's α = .481
Family Housing		x			Constant's α = .365
Operations Buildings		x			Constant's α = .611
Weapons Repair		x			
Maintenance (Missile)	x	x	x		Constant's α = .379 (89% conf. level)
Automotive Vehicle Maintenance		x	x		Constant's α = .589
Training Facilities		x	x		Constant's α = .566
For Training Facilities, Family Housing, D is DF Total					
Training Facilities (SPD)			x		Constant's α = .795
Training Facilities (SAD)		x			

Figure 35. Linear regression analysis of ER 415-345-43 data: DE cost vs. independent variable for in-house work.

Dependent Variable F	A	M	T	X	Remarks
	Independent Variables				
EM Barracks (All)			x	x	Constant's α = .315
EM Barracks (SPD)		x	x	x	Constant's α = .144
EM Barracks (MRD)		x			Constant's α = .683
EM Barracks (POD)				x	Constant's α = .693
EM Barracks (SAD)			x	x	Constant's α = .489
EM Barracks (SWD)	x	x	x		Constant's α = .54
EM Barracks (NAD)					No variables entered
Family Housing (All)					No variables entered
Family Housing (NAD)				F = 0	
Family Housing (SWD)				F = 0	
Family Housing (SAD)		x			Constant's α = .343
Supply (Sq. Ft.)		x			Constant's α = .482
Operational Buildings					No variables entered
Supply (BL)				F = 0	
Weapons Repair	x	x			Constant's α = .842
Aircraft Maintenance					No variables entered
Maintenance (Missile)					No variables entered
Automotive Maintenance					No variables entered
Maintenance Facilities				F = 0	

Figure 36. Linear regression analysis of ER 415-345-43 data: DE superseded or deleted vs. independent variable for contracted work.

Dependent Variable F	Independent Variables A	M	T	X	Remarks
EM Barracks (All)	x			x	
EM Barracks (NAD)			x		
EM Barracks (POD)				No Regressions	
EM Barracks (SAD)					No variables entered
EM Barracks (SPD)	x				Constant's α = .579
EM Barracks (SWD)					No variables entered
Family Housing				F = 0	
Operations Buildings			x		Constant's α = .174
Weapons Repair			x	x	Constant's α = .550
Maintenance (Missile)				F = 0	
Automotive Vehicle Maintenance				F = 0	
Training Facilities (SPD)				F = 0	
Training Facilities (SAD)				F = 0	

Figure 37. Linear regression analysis of ER 415-345-43 data: DE superseded or deleted vs. independent variable for in-house work.

	Independent Variables					
Dependent Variable AET	A	M	G	T	X	Remarks
EM Barracks (All)			x		x	Constant's α = .27
EM Barracks (SPD)			x			Constant's α = .306
EM Barracks (MRD)		x	x			Constant's α = .272
EM Barracks (POD)		x				
EM Barracks (SAD)	x	x	x			Constant's α = .117
EM Barracks (SWD)			x		x	Constant's α = .376
EM Barracks (NAD)	x	x	x		x	Constant's α = .164
Family Housing (All)		x	x	x		Constant's α = .271
Family Housing (NAD)			x			Constant's α = .994
Family Housing (SWD)		x	x	x		
Family Housing (SAD)		x	x			Constant's α = .67
Supply (Sq. Ft.)			x			
Operational Buildings			x			Constant's α = .260
Supply (BL)			x			Constant's α = .172
Weapons Repair		x	x		x	Constant's α = .470
Aircraft Maintenance	x	x	x	x	x	Constant's α = .595
Maintenance (Missile)			x			
Automotive Maintenance						No variables entered
Maintenance Facilities			x			Constant's α = .318
Training Facilities						

Figure 38. Linear regression analysis of ER 415-345-43 data: total A/E cost vs. independent variable for contracted work.

	Independent Variables					
Dependent Variable DET	A	M	G	T	X	Remarks
EM Barracks (All)	x		x		x	Constant's α = .139
EM Barracks (SPD)						Constant's α = .515
EM Barracks (MRD)		x	x			Constant's α = .257
EM Barracks (POD)					x	Constant's α = .736
EM Barracks (SAD)	x			x	x	Constant's α = .275
EM Barracks (SWD)			x			Constant's α = .658
EM Barracks (NAD)	x	x	x		x	Constant's α = .184
Family Housing (All)		x	x	x		Constant's α = .266
Family Housing (NAD)			x			Constant's α = .921
Family Housing (SWD)		x	x	x		
Family Housing (SAD)	x	x				Constant's α = .253
Supply (Sq. Ft.)		x				
Operational Buildings			x			Constant's α = .258
Supply (BL)			x			Constant's α = .172
Weapons Repair			x			Constant's α = .253
Aircraft Maintenance	x	x	x	x	x	Constant's α = .592
Maintenance (Missile)			x			
Automotive Maintenance		x				Constant's α = .724
Maintenance Facilities						No variables entered

Figure 39. Linear regression analysis of ER 415-345-43 data: total DE cost vs. independent variable for contracted work.

Dependent Variable DET	A	M	G	T	X	Remarks
			Independent Variables			
EM Barracks (All)			x			Constant's α = .302
EM Barracks (MAD)						No variable entered
EM Barracks (POD)				No Regressions		
EM Barracks (SAD)			x			Constant's α = .330
EM Barracks (SPD)				No Regressions		
EM Barracks (SWD)				No Regressions		
Family Housing				No Regressions		
Operations Buildings			x			Constant's α = .344
Weapons Repair			x			Constant's α = .335
Maintenance (Missile)				No Regressions		
Automotive Vehicle Maintenance				No Regressions		

Figure 40. Linear regression analysis of ER 415-345-43 data: total DE cost vs. independent variable for in-house work.

	Independent Variables				
Dependent Variable EDR	A	M	T	X	Remarks
EM Barracks (All)			x		
EM Barracks (SPD)					No variable entered
EM Barracks (MRD)			x		
EM Barracks (POD)		x			
EM Barracks (SAD)					No variables entered
EM Barracks (SWD)				x	
EM Barracks (NAD)	x		x	x	Constant's α = .271
Family Housing (All)					No variables entered
Family Housing (NAD)		x			Constant's α = .217
Family Housing (SWD)					No variables entered
Family Housing (SAD)		x			No variables entered
Operational Buildings					No variables entered
Supply (BL)					No variables entered
Weapons Repair					No variables entered
Aircraft Maintenance					No variables entered
Maintenance (Missile)		x	x		Sign. of M = .117
Automotive Maintenance		x			Constant's α = .755
Maintenance Facilities	x	x			Constant's α = .28
Training Facilities	x				
Hospital			x		
Administration Buildings	x		x		

Figure 41. Linear regression analysis of ER 415-345-43 data: ratio of E& D cost to design cost vs. independent variable for contracted work.

Dependent Variable EDR	A	M	T	X	Remarks
Training Facilities (MRD)	x			x	
Training Facilities (SAD)		x	x		
Training Facilities (SPD)		x			
Training Facilities (SWD)	x				
Training Facilities (NAD)		x			

Figure 41. (cont'd)

	Independent Variables				
Dependent Variable EDR	A	M	T	X	Remarks
EM Barracks (All)			x	x	
EM Barracks (NAD)		x	x		Constant's α = .41
EM Barracks (POD)					No variables entered
EM Barracks (SAD)		x		x	
EM Barracks (SPD)		x	x	x	Constant's α = .933
EM Barracks (SWD)					No variables entered
Family Housing		x			Constant's α = .724
Operations Buildings					No variables entered
Weapons Repair		x			Constant's α = .492
Maintenance (Missile)					No variables entered
Automotive Vehicle Maintenance					No variables entered
Training Facilities					No variables entered
Training Facilities (SPD)			x		
Training Facilities (SAD)	x				

Figure 42. Linear regression analysis of ER 415-345-43 data: ratio of E&D cost to design cost vs. independent variable for in-house work.

Independent Variables

Dependent Variable	A	M	B	D	G	X	AET	DET	T
T	1 / .023	1 / 0			1 / .001	2 / 0	1 / .030	1 / 0	
	2 / .314	2 / .029			2 / .002	1 / .045	2 / .024	2 / .038	
V	1 / .353	1 / .770			2 / .538	1 / .008	2 / .550	1 / .765	
	2 / .212				1 / .428	2 / 0	1 / .445	2 / .899	
C	1 / .343	1 / .026				2 / .483			1 / .064
	2 / .284	2 / .052							2 / .403
F	1 / .825	1 / .610							2 / .629
	2 / .710	2 / .695							1 / .605
B	1 / .270	1 / .002				1 / .025			1 / .078
	2 / .077	2 / 0				2 / .703			2 / .267
D	2 / 0	1 / 0				1 / 0			1 / 0
	1 / .864	2 / .560				2 / .391			2 / .824
AET	1 / .200	1 / 0			1 / 0	1 / .028			1 / .030
	2 / .054	2 / 0			2 / .042	2 / .808			2 / .204
DET	2 / .001	1 / 0				1 / 0			1 / 0
		2 / .517				2 / .436			2 / .799
EDR	2 / .660	1 / .779				2 / .700			2 / .799
	1 / .669	2 / .228							1 / .315

KEY → Independent Variable

Dependent Variable ↓

	M
T	1 / 0
	2 / .029

M was entered first into regression at $\alpha = 0$, while M^2 followed at $\alpha = .029$.

Figure 43. Stepwise fit of $f(x) = Ax^2 + Bx + c$ for family housing (contracted).

Independent Variables

Dependent Variable	A	M	B	D	G	X	AET	DET	T
T	1 .023	1 0			1 .001	2 0	1 .030	1 0	
	2 .314	3 .027			3 .001	3 0	2 .024	3 .017	
	3 .590				2 .052	1 .530	3 .420	2 .016	
V	1 .353	1 .770			3 .520	1 .008	2 .550	1 .765	
	2 .212				1 .652	2 0	1 .445	3 .868	
					2 .149	3 0	3 .092	2 .825	
C	1 .343	1 .026				2 .483			1 .064
	3 .225	3 .026				3 .019			3 .179
	2 .506	2 .139				1 .396			2 .009
F	1 .825	1 .610							2 .629
	2 .710	3 .590							1 .605
	3 .203	2 .462							3 .118
B	1 .270	1 .002				1 .025			1 .078
	2 .077	2 0				3 .531			2 .267
	3 .225	3 .356				2 .467			3 .183
D	2 0	1 0				1 0			1 0
	3 .819	2 .560				2 .391			2 .824
		3 .591				3 .002			3 .051
AET	1 .200	1 0			1 0	1 .028			1 .030
	2 .054	2 0			3 .027	3 .485			2 .204
	3 .420	3 .861			2 .405	2 .150			3 .739
DET	2 .001	1 0				1 0			1 0
	3 .809	2 .517				2 .430			2 .633
	1 .502					3 .010			3 .022
EDR	2 .660	3 .753				3 .643			3 .705
	1 .669	1 .374				2 .669			1 .368
	3 .320	2 .059				1 .782			2 .684

KEY

Dependent Variable	Independent Variable M
T	1 0
	2 .029

M was entered first into regression at $\alpha = 0$, while M^2 followed at $\alpha = .029$.

Figure 44. Stepwise fit of $f(x) = Ax^3 + Bx^2 + Cx + D$ for family housing (contracted).

Independent Variables

Dependent Variable	A	M	B	D	G	X	AET	DET	T
T	2 .844	2 .676			1 .151	1 0	2 .788	1 .002	
	1 .890				2 .780	2 .054	1 .534		
V	1 .698	1 .641			1 .051	1 .004	1 .068	1 .445	
	2 .530	2 .333			2 .057	2 .054	2 .052	2 .064	
C	1 .118	1 .068				1 .754			1 .408
	2 .405	2 .029				2 .192			2 .079
F	1 .782	1 .702				1 .508			1 .433
	2 .832	2 .457				2 .521			2 .233
B	1 0	1 0				2 .193			2 .387
	2 0					1 .169			1 .040
D	1 0	1 0				1 .003			1 .003
	2 0	2 .514				2 0			2 0
AET	1 0	1 0			1 0	2 .199			2 .406
	2 0	2 .800			2 .149	1 .148			1 .031
DET	1 0	1 0				1 .006			1 .002
	2 0	2 .429				2 0			2 0
EDR	2 .854	2 .887				1 .065			1 .049
	1 .790	1 .604				2 .172			2 .113

KEY → Independent Variable

Dependent Variable ↓	M
T	1 0
	2 .029

M was entered first into regression at $\alpha = 0$, while M^2 followed at $\alpha = .029$.

Figure 45. Stepwise fit of $f(x) = Ax^2 + Bx + C$ for EM barracks (contracted).

Independent Variables

Dependent Variable	A	M	B	D	G	X	AET	DET	T
T	3 / .725	2 / .676			1 / .151	1 / 0	3 / .727	1 / .002	
	2 / .657				2 / .780	3 / .036	1 / .657		
	1 / .456				3 / .086	2 / .300	2 / .596		
V	1 / .698	1 / .641			1 / .051	1 / .004	1 / .068	1 / .445	
	2 / .530	2 / .333			2 / .057	3 / .036	2 / .052	3 / .059	
		3 / .513			3 / .560	2 / .300	3 / .449		
C	1 / .118	1 / .068				3 / .666			1 / .408
	3 / .280	2 / .029				1 / .236			2 / .079
	2 / .253	3 / .512				2 / .500			3 / .630
F	1 / .782	1 / .702				1 / .508			1 / .433
	3 / .767	2 / .457				2 / .521			3 / .232
	2 / .692	3 / .787				3 / .041			
B	1 / 0	1 / 0				3 / .169			3 / .252
	2 / 0	3 / .720				1 / .425			1 / .104
	3 / .082	2 / .138				2 / .014			2 / .059
D	1 / 0	1 / 0				1 / .003			1 / .003
	3 / 0	2 / .514				3 / 0			3 / 0
	2 / .644	3 / .538				2 / .186			2 / .072
AET	1 / 0	1 / 0			1 / 0	3 / .169			3 / .256
	2 / 0	2 / .800			2 / .149	1 / .383			1 / .083
	3 / .117	3 / .123			3 / .490	2 / .015			2 / .058
DET	1 / 0	1 / 0				1 / .006			1 / .002
	3 / 0	2 / .429				3 / 0			3 / 0
	2 / .599	3 / .514				2 / .097			2 / .080
EDR	3 / .850	3 / .816				1 / .065			1 / .049
	1 / .890	1 / .686				2 / .172			2 / .113
	2 / .630	2 / .700				3 / .035			3 / .010

KEY

Dependent Variable	Independent Variable M
T	1 / 0 2 / .029

M was entered first into regression at $\alpha = 0$, while M^2 followed at $\alpha = .029$.

Figure 46. Stepwise fit of $f(x) = Ax^3 + Bx^2 + Cx + D$ for EM barracks (contracted).

delay time. A detailed evaluation of this area might uncover a method of significantly reducing overall design time.

Nine phase projects seem to require the same amount of design time, regardless of whether they are original designs; this should be examined in detail.

Activities requiring a large amount of resources during active design were identified. Operating procedures should be examined to determine areas of potential savings.

4 TRENDS IN DESIGN METHODOLOGY MANAGEMENT, AND STRUCTURE

Modifications in the E&D process must take into consideration the prevailing trends in design methodology, construction techniques, and design and construction management. The potential impact of these design process trends must be anticipated and prepared for. This chapter examines some of these trends and their potential impact on the E&D process.

Trends in Design Methodology

Recently, design has been influenced by several important factors, among the most salient of which are increased complexity of the systems to be designed, and additional demands on the system's performance, particularly with respect to impact on the environment and consumption of resources. The practice of design has also been influenced by new production and construction processes (such as industrialized buildings), the recent developments in system engineering operations research, and computer technology.

Systematic Design

During the last two decades, academic and research institutions, as well as design practitioners, have tried to improve design methods and processes. The aim has been to systematize the design process to simplify the design effort, eliminate design errors, improve documentation, and explore a broader range of alternatives to satisfy users' needs. The ultimate goal of many developmental efforts was to transform the design process into a completely programmable closed system, where inputs of performance specifications would be transformed automatically into final designs. Other researchers adopted the more modest goal of systematizing the design process in a manner that could augment, but not replace, the efforts of individual designers. At any rate, a systematization of the design process is a prerequisite to its automation.

Regardless of the ultimate goal of developmental efforts, approaches to a more systematic design process are characterized by the following features:

a. A focus on user requirements, favorably expressed in terms of performance specifications, but possibly in terms of design requirements of the total product (facility).

b. An emphasis on the mission and function of the system designed. This emphasis is popularly referred to as "the system

approach." A system is divided into subsystems and components to facilitate its analysis and design. Consideration is also given to the total life cycle of the facility being designed rather than only the initial costs.

c. An explicit consideration is given to the steps involved in the design process. One general categorization of these steps is analysis, synthesis, and evaluation.

d. Consideration is given to the information requirements and decision criteria and to alternatives required at every step of the design process.

e. The intensive use of models for information organization and presentation and for decision-making. Models can be graphical, logical, or mathematical. Optimization and simulation techniques are occasionally used to select a solution from the available alternatives.

Automated Design

Limited success has been achieved in developing completely automated design systems. Some of the main sources of difficulty are:

a. It was often infeasible to define the performance criteria of a facility and hence to develop performance specifications for it. Such aspects as comfort, convenience, and aesthetic qualities are hard to measure.

b. It was not always possible to build models that incorporate all variables and relationships influencing a design decision. Even when such a model could be built, it was difficult to derive solutions from it because of the enormous number of alternative solutions which it provided.

c. Automated design systems have not been popular with designers who felt that these systems would hamper their creativity.

Systems in which success with automated design has been experienced are those in which the engineering rather than the architectural or artistic aspects were dominant. It is easier to automate the design of the structural subsystem than to automate the selection of the building concept. Interactive design systems evolved as a compromise between extreme reliance on automated design systems and extreme reliance on individual capabilities. They were intended to augment, rather than replace, the individual design effort. They follow the same steps of automated design, except that the designer interjects his own judgments and decisions throughout the design process. The programmed system is referred to whenever it will provide a quicker, less costly, or more accurate answer. Three tools used in modern

design methods--abstract models, modular design techniques, and computer-aided design--are discussed below.

Several forms of abstract models are becoming useful in the design process. A variety of graphical methods has already become commonplace in design. Interaction charts reflect the desirability of connections among spaces within a facility and can be applied to layout design. Set theory, graph theory, and Venn diagrams are used to analyze and regroup user's requirements, preferences, and prohibitions (misfit variables).[12] Most of the available abstract techniques are used to organize information into more useful decision-making data and to derive quantitative solutions to those design aspects expressable in numbers.[13]

The excessive and continually rising costs of facility construction can be attributed mainly to the inefficiency inherent in construction operations. Facilities are built either individually, or in small groups at best; work proceeds in discrete steps and not in continuous flow; in addition, operations are performed under unpredictable environmental conditions that often cause frequent interruptions. The realization that facility components can be produced more efficiently and inexpensively in a factory's more controlled environment has led to increased industrialization of building components. An earlier version of industrialized buildings is prefabricated housing. Presently, industrialized building components cover a broad variety of building subsystems, such as frames, cladding, roofing, and interior. In some cases, fully integrated and manufactured buildings are available, such as pre-engineered metal buildings and mobile homes. Some simple forms of industrialized components have already been adopted by the Army, e.g., prefabricated buildings and prefabricated panel construction. Extending industrialization to a broader range of components and building types is presently being considered. Industrialized buildings offer significant potential advantages; however, realization of the full benefits will require certain modifications to the E&D process.

Introducing industrialized buildings into civilian construction has been associated with the following trends in the total-design procurement-building process:

(1) Significant shifts in the design effort from the owner's contracted A/E to the manufacturer.

---

[12] C. Alexander, "Determination of Components for an Indian Village," J. C. Jones and D. G. Thornley, eds., *Conference on Design Methods* (1963).

[13] C. Alexander, "The State of the Art in Design Methodology," *D. M. G. Newsletter* (March 1971), pp 3-7.

(2) Increased use of "phased" construction, which allows some construction before all design is completed.

(3) Application of new contracting procedures which allow multiple-contracting, in contrast to single-contracting with a general contractor. This trend has led to the introduction of new concepts in construction management, such as the new role of the project manager.

(4) Increased accommodation of the system of codes and standards to industrialized building products and systems.

Standard designs of repetitively constructed facilities have been used by the U.S. Army for some time. Design modifications for site adaptation and requirement changes have been used whenever necessary. Using standard designs is supposed to offer great savings in design costs and time. They are most useful where like facilities are constructed in large numbers and are subject to minimal site adaptation and requirement changes. On the other hand, standard designs are constrained by their lack of adaptability to use different materials, employ different construction processes, and fit into different environments. With continually rising material and construction costs and expanding environmental constraints, these considerations are important in any design. Modular design concepts aim at achieving the required flexibility of standard designs while retaining many of their advantages. The focus here is on standardizing the overall dimensions of facility components rather than their detailed design. Facility components thus constitute three-dimensional modules which interface with other components along lines and surfaces of standard dimensions. One important advantage of this approach to the designer is a narrower range of choice between alternative dimensions; a broader range does not add significant benefits. Thus, the design process is simplified and speeded. Another important advantage is that manufacturers of industrialized or prefabricated components will produce components which can interface with those of other manufacturers, allowing the designer more freedom to choose subsystems.

Computer-aided design was initially designed to implement fully automated design systems. Although possibilities of completely automated design are still being examined, this process is used mostly in an interactive mode. The advantage of computer-aided design is that it forces designers to be more objective and specific about defining design selection criteria.

Automation also alleviates the generation of estimates (especially costs) and the process of checking designs against codes, regulations, specifications, and internal consistency.

Trends in Design Management

District design office E&D management functions include:

(a) Projecting the design load

(b) Acquiring design resources (hiring personnel, training, procuring instruments, materials, and references for design).

(c) Developing resources (assigning projects to sections and personnel, allocation of budget).

(d) Monitoring design progress, cost, and quality.

(e) Procuring A/E's for out-of-house designs.

(f) Maintaining an adequate information system (references, cataloging of designs, progress reporting).

(g) Evaluating design effort.

Project Management Information Systems

Among the most powerful project management tools are project planning and resource allocation systems. Several management information systems have been developed for multi-project analysis. These are proprietary systems which have been tailored to meet the needs of a particular management organization. Generally, these systems seek to provide information to decision-makers in a hierarchical management organization by scheduling construction operations and by allocating resources to the operations. In all these systems, heuristic decision rules are used to evaluate alternative courses of action; the system relies heavily on man/machine interaction to provide acceptable project and resource schedules.

New Construction Management Approaches

The new trends in design methodology and construction technology have affected construction management. To varying degrees, new directions in construction management have been adopted by the government and by the commercial sector. The underlying motive behind most of these changes is the realization that a project consists of a distinct set of facilities or subfacilities (modules) that can be designed and constructed independently, with design integration only at the interfaces between the modules. Such realization led to the following changes:

(1) Multiple contracting. The design and/or construction of a module or group of modules is assigned to a separate contractor. The

owner or his representative will then coordinate the different design and construction efforts.

(2) Phased construction. The division of a facility into modules allows the overlapping of design and construction activities so that the construction of one module (for example, a building frame) may start before the design of another module is completed (for example, cladding). Phase construction has definite advantages over traditional construction, which schedules the main phases of design-bid-build serially. The main advantages are saving time and avoiding prolonged project implementation which might increase construction costs.

(3) Project manager role. The role of the project manager emerged when it became necessary to have a representative of the owner to coordinate the activities of different contractors.

(4) Integration of design and construction. With the increased use of industrialized components and modules, manufacturers have acquired more design responsibility. The role of an A/E contracted by the user focuses more and more on the specification of the overall requirements of the modules and the interfaces between them.

Trends in the Structure of the Design Process

The E&D process is an integral part of the total decision-making process involved in the design and construction of Army facilities. Several factors are forcing a reappraisal of the MCA cycle, including the new construction technology and the rising costs of design and construction. The methodology of design is being studied for possible adoption of computer-aided design and other new methods for Corps projects. A research study entitled "Automated Engineering and Architecture Design System (AEADS)" is being conducted at CERL for that purpose. E&D management is being influenced by new management information systems (such as RA/PM [Resource Allocation/Project Manager]) and new construction management trends (such as the new role of project management). Certain aspects of the MCA process have been considered for possible modification, including procurement sequences, contracting strategies, and construction strategy. Since the steps of the MCA process are intertwined, a change in one will affect most others. Thus, process should be considered as a whole before changes are introduced to any part. To assist with an overall assessment of the effect of changes, the following briefly summarizes the main options available in the areas under consideration in this section:

Options for the MCA Cycle:

(1) Procurement sequences and options

(a) Design-bid-build

. Conventional method

. Conventional method with performance specifications

. Conventional method with pre-identified hardware

(b) Bid-design-build

. Responsive low bid

. One-step competitive negotiations

. Two-step formal advertising

(2) Contracting strategies and management responsibilities

(a) Single contract

. General contractor manages construction and subcontracts to special contractors

. District engineer or A/E monitors construction

(b) Multiple contracts

. District engineer or project manager oversees project, coordinates special contractors, and monitors construction

. Allows owner to choose the best available special contractor

(3) Construction strategy

(a) Nonphased construction

(b) Phased construction

Impact of New Trends on E&D

Some options of the MCA cycle fit together, while others are incompatible. For example, the full advantages of multiple contracting are not realized unless phased construction is used. Furthermore, certain construction technologies and design methodologies require, or work best under, specific options. For example, the best options with industrialized building are: conventional procurement with either performance specification or pre-identified hardware, or responsive-low-bid procurement; multiple contracting; and phased construction.

The options chosen will affect the E&D process. For example, the *bid-design-build procedure*, as well as *conventional procurement* with performance specifications, shifts the main effort of detailed design from the Corps or the A/E to the contractor. It should also be added that the same effect will occur with industrialized buildings regardless of the option chosen. This shift will affect the structure of the E&D process, as well as the skill types and levels of design personnel.

5. E&D PROCESS MODELING REQUIREMENTS

The two fundamental requirements of any model are: (1) it should be a valid description of the system studied, and (2) it should be usable for its intended purposes.

Precedence Relationships

The network model used in the Chapter 2 description of the design process was a CMP/PERT-type network. CPM/PERT networks represent significant developments in the methodology of project analysis. They force the analyst to clearly define the project and its scope; highlight the interdependence among the project activities; provide a means for estimating project duration; identify "slack" and "critical" activities; and furnish a basis for the development of useful management information systems. However, to use this method, certain assumptions have been made in the construction of the existing E&D process networks:

a. *All* the predecessors of an activity must be completed before the activity can start.

b. When all predecessors of an activity are completed, the activity *will start* at some definite time in the future.

c. When an activity starts, it *will be completed* at some definite time in the future.

These assumptions are inherent in CPM/PERT networks, which belong to the class of "deterministic networks." In terms of activity-on-arc* network representation, the assumptions mean that all the nodes in the network represent the following two logical operations: (1) an "AND" operation on the input side, meaning that *all* activities impinging on the node must be completed for the node to be realized; and (2) a "DETERMINISTIC" output, implying that realization of the node triggers the release of *all* succeeding activities. The assumptions of deterministic networks lead to the following conclusions: the project always ends in success; all activities represented in the network will be executed; and once an activity is completed, there is no way in which it can be repeated except by representing it with a different arrow in the network, in which case the repetition is considered to be a predetermined eventuality.

While the assumptions were necessary to facilitate the initial phases of data collection and modeling, it is clear that the typical

---

* Same as activity-on-arrow.

E&D project violates the conditions inherent in deterministic networks. Projects which are started may be suspended and perhaps eventually abandoned; the sequence of activities involved in a design project varies from one project to another, so that an all-encompassing network will contain activities which may not be included in any one particular project; in addition, design tasks may be repeated for an unpredetermined number of times as a result of either errors discovered at a later stage or modifications required by the user. In order that a model be a more valid description of the E&D process, these assumptions must be removed. The conditions which will be introduced with the removal of the assumptions dictate the use of more generalized network models. The anticipated uses of an accurate model of the E&D process can be summarized as follows:

a. To obtain a clear and precise representation of the total process

b. To identify potential areas of improvement

c. To test the effect of modification in the process

d. To be used as a planning tool: estimation of future workloads; decision-making such as for contracting versus in-house design; estimation of resource requirements for design (including cost); allocation of jobs to personnel; anticipation of bottlenecks, delays, and cost overruns

e. To be used as a tool for control: checking progress against plans; selecting monitoring points

f. To serve as an aid in budgeting and planning of personnel recruitment.

The first three functions are related to the process structure, while the other three are concerned with its management. An extension of the present study would be necessary to address all six requirements.

Models to be Developed

Single-Project Modeling

A complete network model of the process structure should contain the sequence of activities necessary to complete any single-design project as a path in the network from its start node to its finish node. The realization of a particular sequence in a given project depends on the project's characteristics, procurement policies, design policies, recycling requirements, and a number of probabilistic factors, some of which are not controllable. The master network should be free of

the constraining assumptions of the existing networks and should be usable for testing the effect of changes in the process.

Multiple Project Modeling

Design management involves the coordination of a number of design projects conducted concurrently or sequentially. Thus, for use as a management tool, the capability of the single-project model should be extended to accommodate the concurrent accounting of several projects in terms of time, cost, and resource use.

Both of the above models of the process can be used only if they are supported by an appropriate management information system (MIS). The MIS will act as an intermediary between the real system and the modeling, feeding the model-relevant information in appropriate format and providing management with the necessary reports. The MIS should also furnish information not necessarily related to the model, but which is needed by management, such as available standard designs and construction materials.

Available Modeling Methods

Two network models, graphical evaluation and review techniques (GERT)[14,15] and generalized activity networks (GAN),[16] referred to often as "stochastic networks," have the capability to incorporate a project's uncertainties. The two stochastic network models accomplish this by introducing additional logical relationships among activities. While such relationships have been described recently on activity-on-node networks,[17] they are more commonly portrayed on activity-on-arrow networks, where the nodes represent logical relationships. In addition to the "AND" input and the "DETERMINISTIC" output characteristic of CPM and PERT networks, GERT and GAN embody two additional logical relationships. The first is an "OR" input, signifying that one (EXCLUSIVE OR), or some (INCLUSIVE OR), but not all of the

---

[14] Jerome D. Wiest, *Computer Models for the Scheduling of Large Projects*, PhD thesis (Carnegie Institute of Technology, 1964).

[15] Jerome D. Wiest, "A Heuristic Model for Scheduling Large Projects with Limited Resources," *Management Science*, Vol 13, No. 6 (February 1967), pp B359-B377.

[16] Bernard Combe, "Description of a Resource Allocation Program ASTRA-DISC," *Project Planning by Network Analysis*, Lombaers (ed.), (North-Holland Publishing Company, Amsterdam, 1969), pp 243-248.

[17] Louis Gonguet, "Comparison of Three Heuristic Procedures for Allocating Resources and Producing Schedule," *Project Planning by Network Analysis*, Lombaers (ed.) (North-Holland Publishing Company, Amsterdam, 1969), pp 249-255.

activities impinging on a node are necessary to realize the node. The second additional logical feature is a "PROBABILISTIC" output, allowing for one and only one of the activities emerging from a node to be initiated, based on a set of realization probabilities assigned to the emanating activities. Naturally, the sum of the probabilities of realization of all arcs emanating from any node must be unity. These additional logical input and output features provide a flexibility which makes it possible to incorporate activities which can start as soon as a subset of preceding activities has been completed, and allow for feedback and repetition of activities to take place.

In addition, the arcs of GERT and GAN carry more information than those of PERT or CPM. They are multiparameter, with the parameters representing the probability of realization, the probability distribution of arc duration, and the distribution parameters. Additional parameters could be the cost of completing the activity, which may be a constant or a function of duration; the resources required; or any other parameters relevant to the analysis. GERT and GAN do not use only beta distributions for activity durations as PERT does, but allow a wide variety of probability distributions. More importantly, they use the distribution itself, rather than merely its mean, in subsequent analysis.

Simulation of the Design Process

Experience and past studies decisively demonstrate that analytic solutions of stochastic network problems are only feasible for the very simplest networks. This suggests that simulation may be the only tractable approach to the analysis of such networks. GERTS III,[18] a FORTRAN-based simulation program, has been especially designed to simulate GERT networks. In addition to including the features described for GERT networks above, GERTS III has the capability of modifying the network and removing specified arcs when specified events occur. There are presently three additional versions of GERTS III[19] which have specific additional capabilities: GERTS III[20] for resource allocation, GERTS IIIC for cost accounting, and GERTS IIIQ for keeping

---

18 Chandra K. Jha, "T-COM, A Construction Management Information System," paper presented to the Fourth Annual International Seminar Symposium of the Project Management Institute, Philadelphia, Pennsylvania (October 1972).

19 Chandra K. Jha.

20 N.M.L. Barnes, and J. S. Gillespie, "Computer-Based Cost Model for Project Management," *INTERNET 72*, Book III, Third International Congress on Project Planning by Network Techniques, Stockholm, Sweden (May 1972), pp 37-58.

track of queues. A recently developed version, GERTS IIIQR,[21] combines GERTS IIIR with GERTS IIIQ.

While GERTS III, with all its versions, provides a very strong tool for analyzing stochastic networks, it is still lacking in the following respects:

a. A considerable amount of modeling is needed to transform the raw data into information suitable for feeding into the programs.

b. The variety of output statistics is inadequate, and output is not provided in a form immediately usable by management for planning and control decisions.

c. It has no capability for automatic decision-making or optimization.

A recently developed system (Generalized Network Simulator - GNS)[22] incorporates the modeling capabilities of GERTS III and its extensions but has additional features to overcome the inherent GERTS deficiencies. At this time, the simulation of the E&D process seems feasible with this system.

---

21 Julia Balla and Antal Szolnoky, "Construction Industry Programming System," *INTERNET 72*, Book III, Third International Congress on Project Planning by Network Techniques, Stockholm, Sweden (May 1972), pp 23-26.

22 K. Tonegawa, "Generalized Stochastic Networks and Generalized Network Simulator," PhD dissertation (Department of Mechanical Engineering, University of Illinois, 1974).

6 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Design Activities

The design process has been represented by a general activity network of 127 quantifiable activities: 13 for environmental impact statements, 30 for A/E procurement and District Engineer predesign, 53 for preconstruction design, 13 for advertisement and award, and 18 for design modification activities.

Design Data

One of the five bodies of project time and cost data required has been analyzed in full--the Fort Worth District detailed project data--itemizing design activity costs and time to the sectional organization level and for the preliminary, advanced final, and final design periods. Two other sets of data have been partially evaluated: (1) ER 415-345-43 project data, (2) MIDAS project data (A/E procurement, nine design periods from directive through ready-to-advertise, and advertisement and award). The A/E procurement, District Engineer predesign, and advertisement and award data have been received but not analyzed. A satisfactory source for design modification (during construction) data is being sought.

Data Analysis

Procedures for analyzing current and reasonably certain future data have been planned. Strong correlations between total time and total cost, among component times, and among component costs were observed.

Conclusions

Most of the conclusions to be drawn from this study will depend on future analyses. Work to date has emphasized description of the process, data acquisition, and some limited data analyses. A few conclusions can be made, however.

It is possible to represent the overall design process by a reasonably large, yet tractable, number of activities which are influenced by a relatively few controlling variables, such as control cost, facility class and construction category, and type of funds. However, if these activities are to be quantified, there must be a commonality of network representation among projects, and there must be a practical limit to the number of activities for which data are recorded.

The multiple regression analysis procedure of the Statistical Program for the Social Sciences (SPSS) has proven to be a simple and effective tool for analyzing historical design activities-time-cost records of the activity network and progress reporting types. However, meaningfulness of the results depends on data homogeneity, sample sizes, and representativeness of the data. Considering the number of variables influencing design, good historical records of projects would be desirable. Therefore, a number of District offices must pool their data.

Meaningful relations among design variables can be obtained when data have been edited properly to reject those having illogical relations among the variables. It has been found that traditional visual and machine checking, while insuring minimum standards for purposes of activity network and progress reporting analyses, lacks the rigor required for insuring consistent relations among data for a given project. There are design projects with neither design time nor cost, design time but no design cost, design cost but no design time, negative design times, and rates of design expenditure (during active design, not review or delays); this implies that there are fewer than 1/25 and more than 400 men per project per working day--clearly a physical impossibility.

When considering alterations which may be made to the basic process, two factors stand out. First, concerning A/E procurement, there are no maximum time requirements for approvals by a given office, unlike the 10-day agency response time currently required under the Freedom of Information Act. Secondly, consecutive design and construction appears to be used universally, whereas various concurrent design and construction options are available. Concurrent design and construction is called "phased construction" by GSA, and is sometimes called "fast-tracking." A German variant is "tender design." "Turnkey," or "design and build" procurement allows, but does not presuppose, concurrency.

Recommendations

Research required to fully analyze the topics discussed in this report must be completed before drawing definite conclusions which would result in positive recommendations to improve E&D performance. Among the items to be completed are:

a. Analysis of data supplied by District and Divisions on: A/E procurement and District Engineer predesign activities, and advertisement and award activities.

b. Acquisition and analysis of design modification (during construction) activities data.

c. A completion and combination of the results of the data analysis.

d. In-depth evaluation of the reasons causing the observed expected results from the preceding three items.

e. Testing the impact of various design operational procedures via computer simulation.

REFERENCES

Alexander, C., "Determination of Components for an Indian Village," J. C. Jones, and D. G. Thornley, eds., *Conference on Design Methods* (1963).

Alexander, C., "The State of the Art in Design Methodology," *D.M.G. Newsletter* (March 1971), pp 3-7.

Balla, Julia and Antal Szolnoky, "Construction Industry Programming System," *INTERNET 72*, Book III, Third International Congress on Project Planning by Network Techniques, Stockholm, Sweden (May 1972), 23-26.

Barnes, N.M.L., and J. S. Gillespie, "Computer-Based Cost Model for Project Management," *INTERNET 72*, Book III, Third International Congress on Project Planning by Network Techniques, Stockholm, Sweden (May 1972), pp 37-58.

Combe, Bernard, "Description of a Resource Allocation Program ASTRA-DISC," *Project Planning by Network Analysis*, Lombaers (ed.) (North-Holland Publishing Company, Amsterdam, 1969), 243-248.

The Decision Logic Table Technique, AFP 5-1-1 (Department of the Air Force, September 1965).

Drew, D. R., et al., *Investigation and Study of Corps of Engineers System Approach to Design and Construction for Military Construction*, Technical Report 68-041/AD840174 (Texas A&M Research Foundation, May 1968).

Foster, R. L. and B. A. Berson, *Military Construction Contract Management: Tabulation of Responses to the November 1974 Questionnaire*, Technical Report P-35 (Construction Engineering Research Laboratory [CERL], January 1975).

Gonguet, Louis, "Comparison of Three Heuristic Procedures for Allocating Resources and Producing Schedule," *Project Planning by Network Analysis*, Lombaers (ed.) (North-Holland Publishing Company, Amsterdam, 1969), 249-255.

The GSA System for Construction Management, revised edition, Technical Report GSA DC 75-9492 (General Services Administration, April 1975).

Halpin, D. W. and R. D. Neathammer, *Construction Time Overruns*, Technical Report P-16/AD766725 (CERL, August 1973).

Jain, R. K., et al., *Handbook for Environmental Impact Analysis*, Technical Report E-59/ADA006241 (CERL, September 1974).

Jha, Chandra K., "T-COM, A Construction Management Information System," paper presented to the Fourth Annual International Seminar Symposium of the Project Management Institute, Philadelphia, Pennsylvania (October 1972).

McCoy, P. T. and C. R. Sprague, *Systems Analysis of Corps/A-E Design Engineering*, Technical Report 69-041/AD865247 (Texas A&M Research Foundation, June 1969).

McDaniel, H., *Decision Table Software--A Handbook* (Brandon/Systems Press, Inc., 1970).

McDaniel, H., editor, *Applications of Decision Tables--A Reader* (Brandon/Systems Press, Inc., 1970).

Pollack, S. L., et al., *Decision Tables: Theory and Practice* (Wiley-Interscience, 1971).

Smith, G. D. and D. A. Krausse, *A Study to Determine If Design and Build Procurement Methods for Military Family Housing Are More Economical Than Conventional or Two Step Methods*, Technical Report SLSR-28-72B/AD750919 (Air Force Institute of Technology, September 1972).

Tonegawa, K., "Generalized Stochastic Networks and Generalized Network Simulator," PhD dissertation (Department of Mechanical Engineering, University of Illinois, 1974).

Wiest, Jerome D., *Computer Models for the Scheduling of Large Projects*, PhD thesis (Carnegie Institute of Technology, 1964).

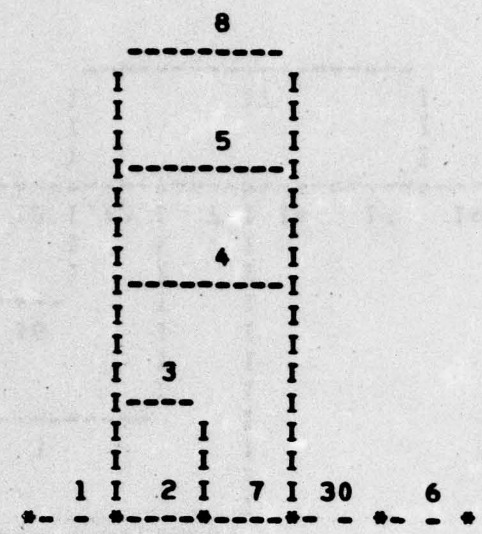
Wiest, Jerome D., "A Heuristic Model for Scheduling Large Projects with Limited Resources," *Management Science*, Vol 13, No. 6 (February 1967), pp B359-B377.

APPENDIX A:

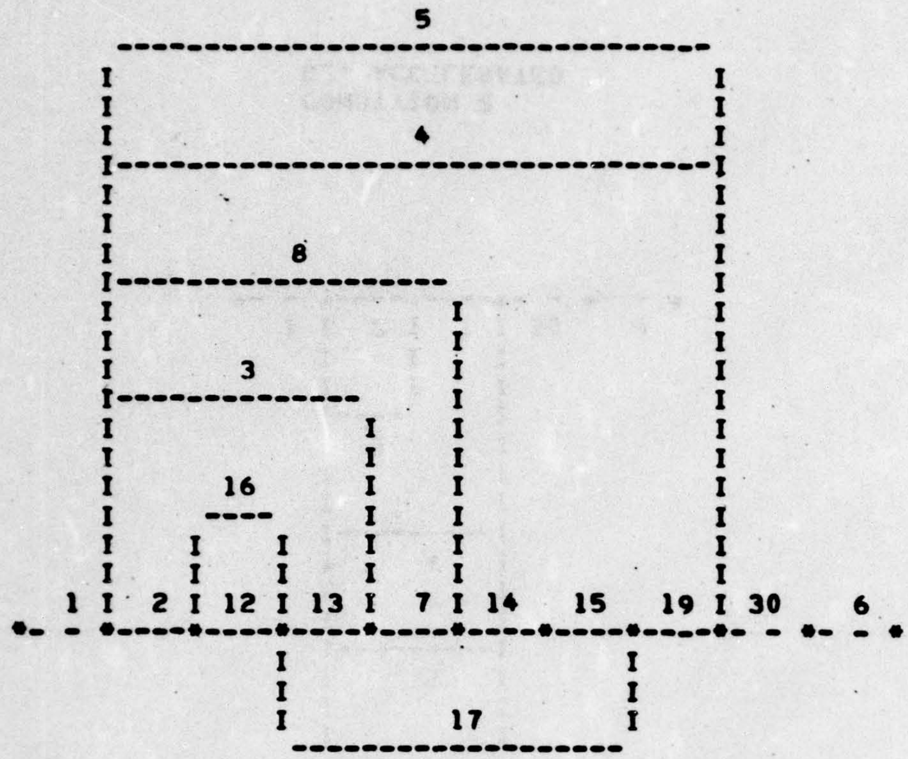
FIGURE 7 DECISION LOGIC TABLE

```
       5
      ----
     I    I
     I    I
     I  4 I
     I----I
     I    I
     I    I
     I  3 I
     I----I
     I    I
     I    I
  1  I  2 I 30     6
*- - *----*- -  *- - *
```

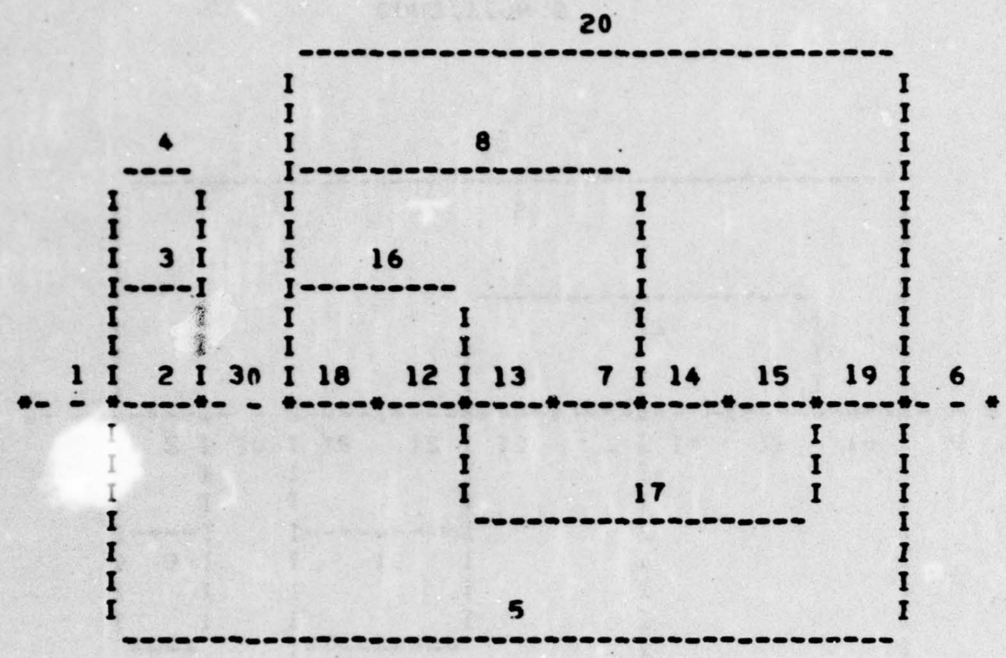
CONDITION 1
DE, NORMAL ARMY



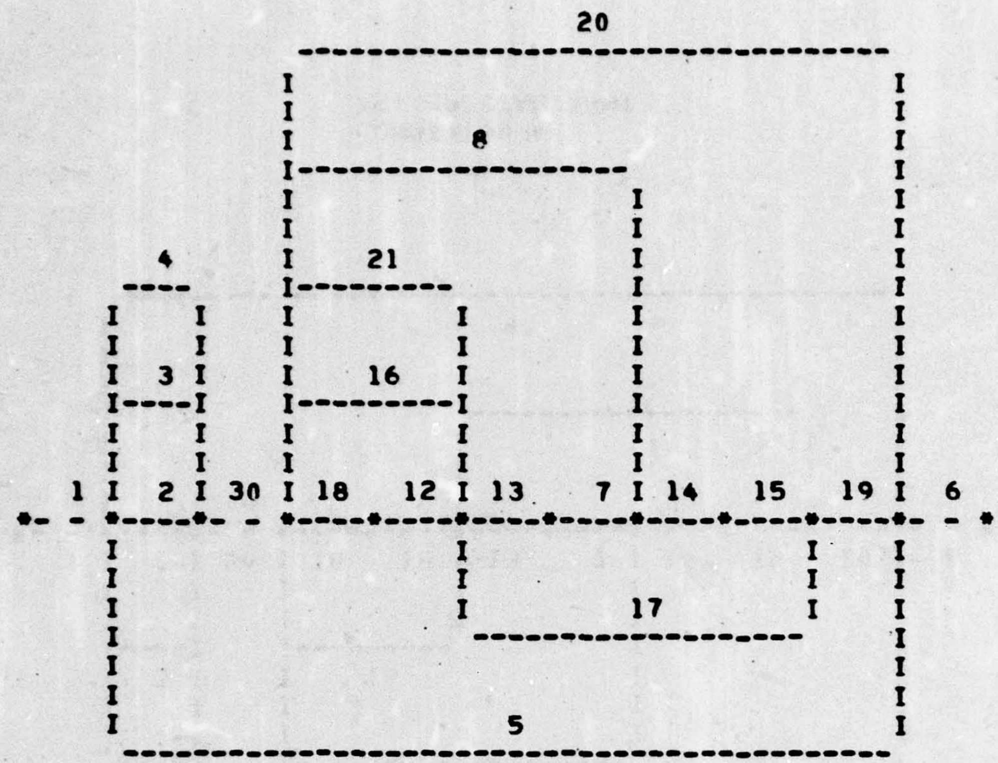
CONDITION 2
DE, ACCELERATED



CONDITION 3
AE, ACCELERATED



CONDITION 4
AE, SPECIAL ARMY



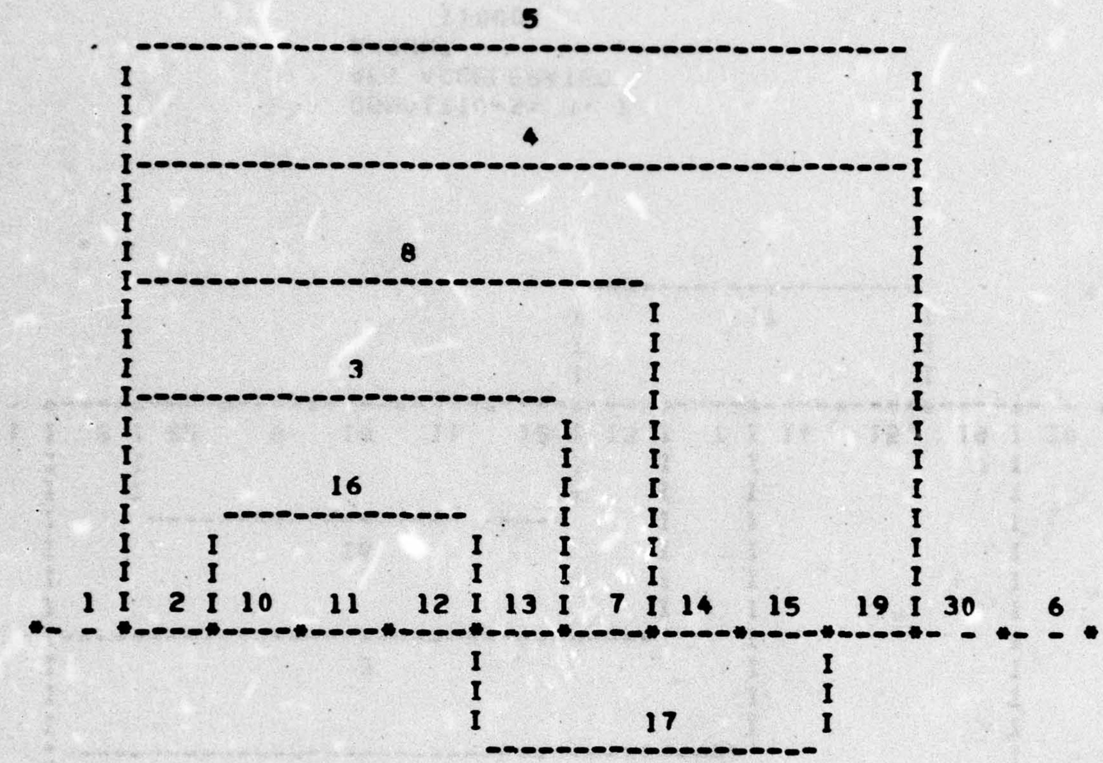
CONDITION 5
AE, NORMAL ARMY

```
          5
         ----
        I    I
        I    I
        I  4 I
        I----I
        I    I
        I    I
        I  3 I
        I----I
        I    I
        I    I
     1  I  2 I 30    6
  *-  - *----*----*-  - *
```

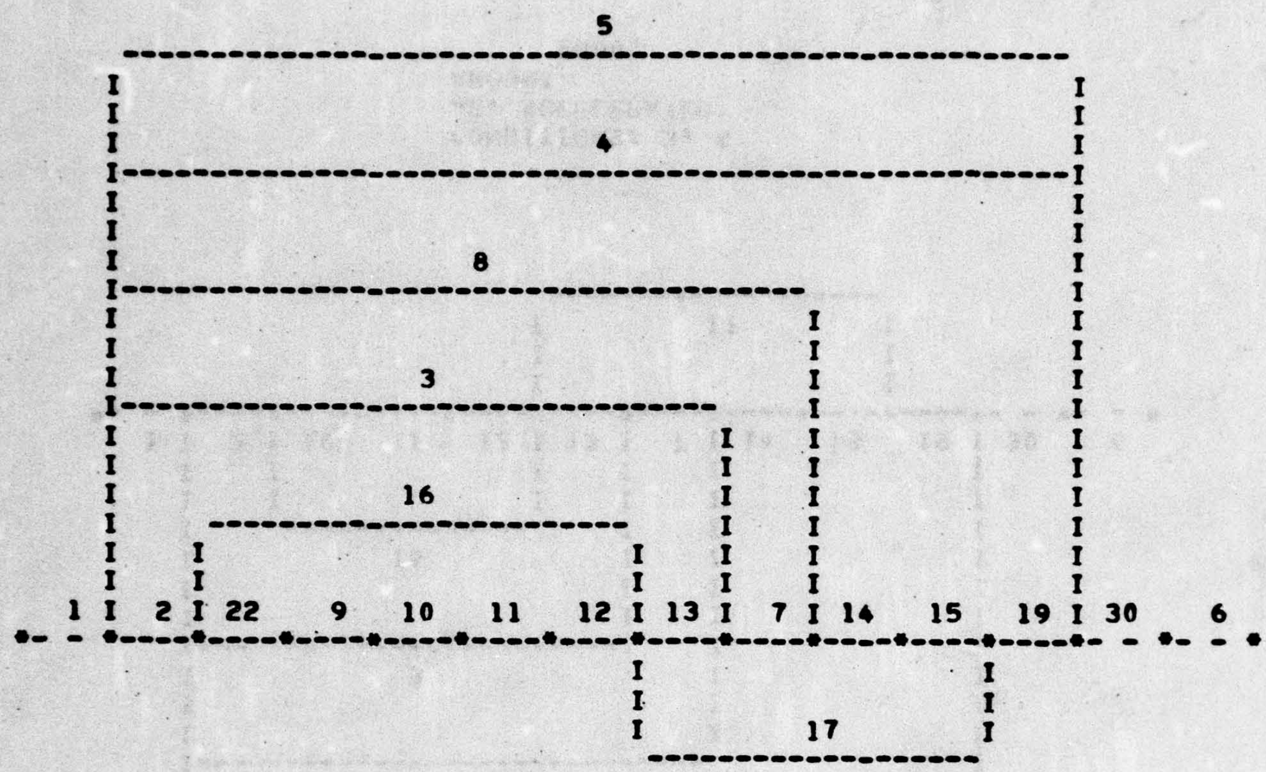
CONDITIONS: 1, 16
DE, NORMAL ARMY
DE, DELAY IN DES DIRECTIVE

```
              8
          ---------
        I           I
        I           I
        I     5     I
        I-----------I
        I           I
        I           I
        I     4     I
        I-----------I
        I           I
        I           I
        I  3        I
        I----       I
        I     I     I
        I     I     I
     1  I  2  I  7  I 30    6
  *-  - *-----*-----*-----*-  - *
```

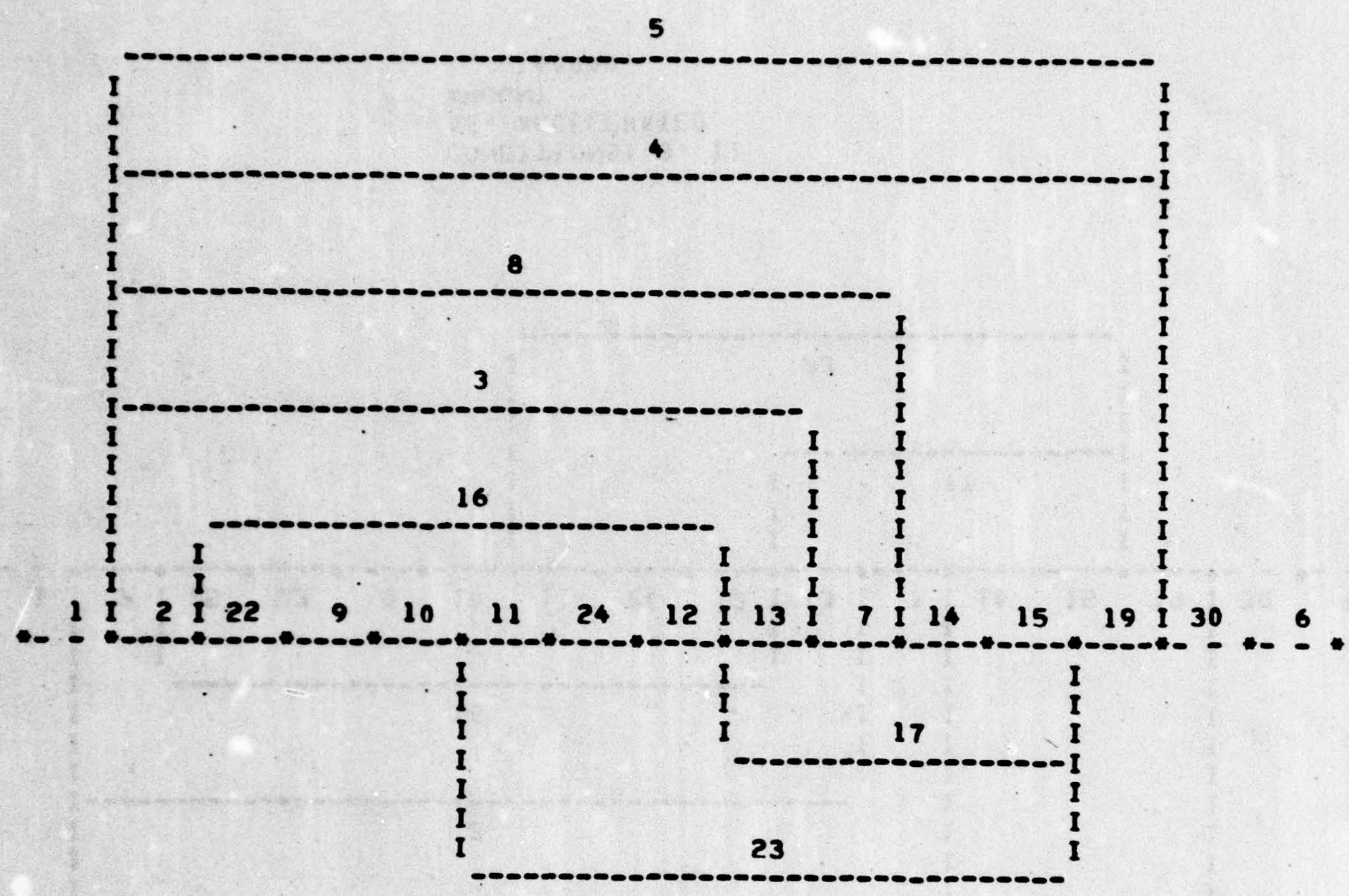
CONDITIONS: 2, 16
DE, ACCELERATED
DE, DELAY IN DES DIRECTIVE



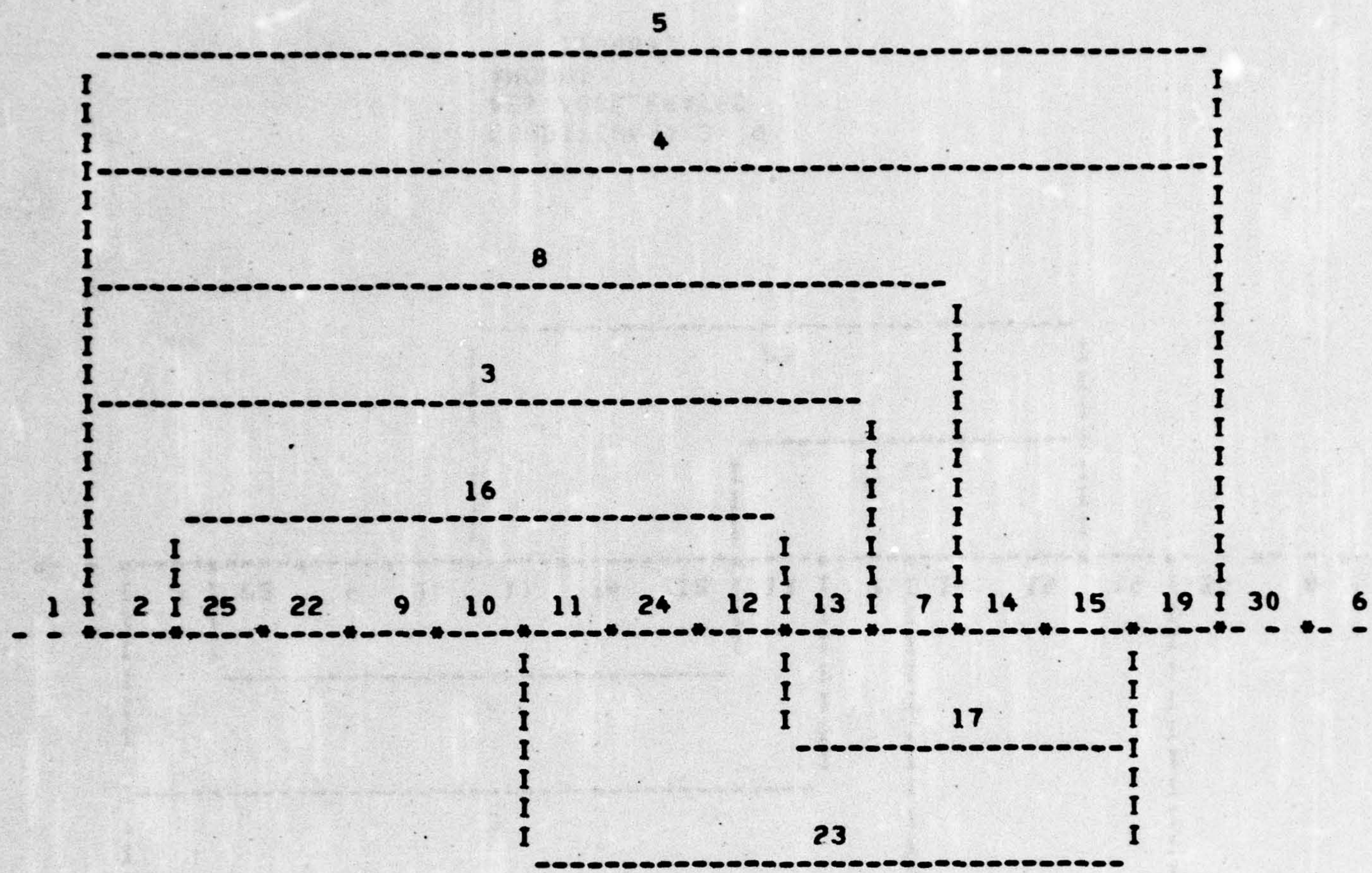
CONDITIONS: 3, 6
AE, ACCELERATED
AMOUNT
2600.



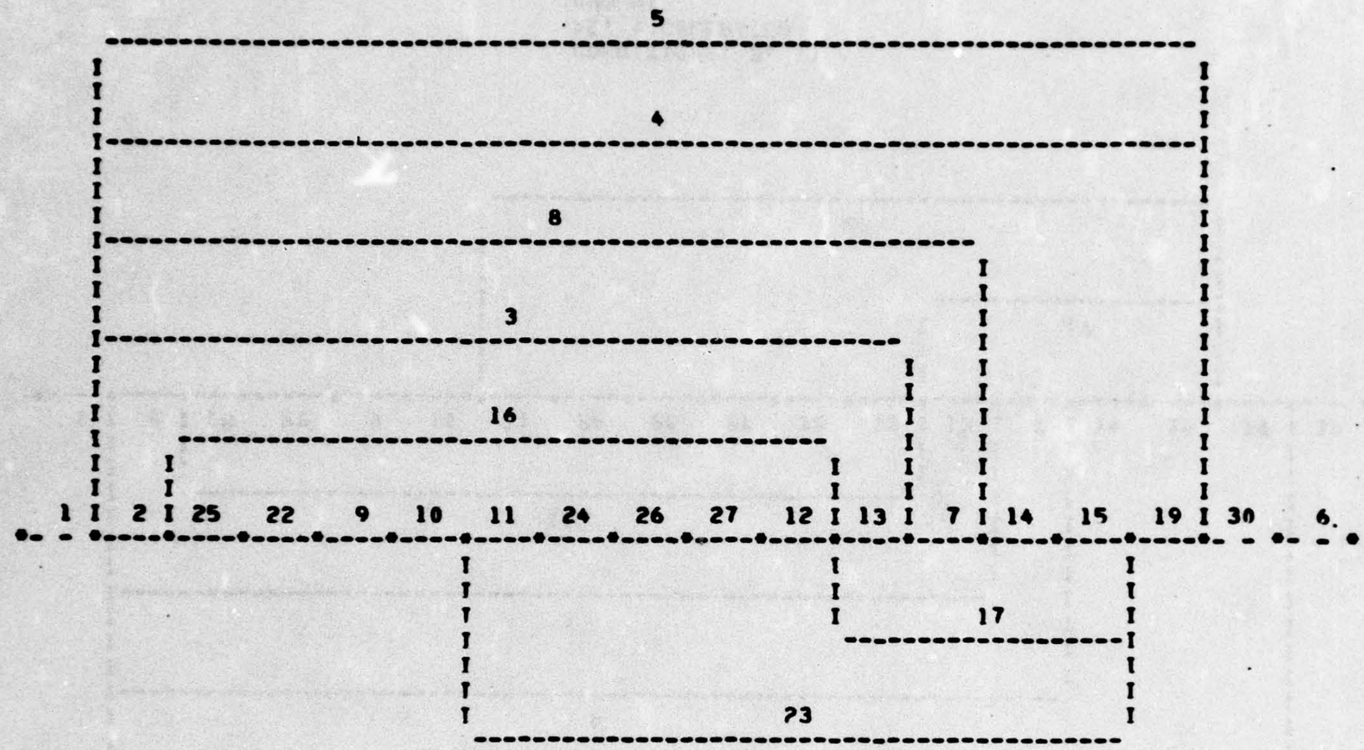
CONDITIONS: 3, 7
AE, ACCELERATED
AMOUNT
11000.



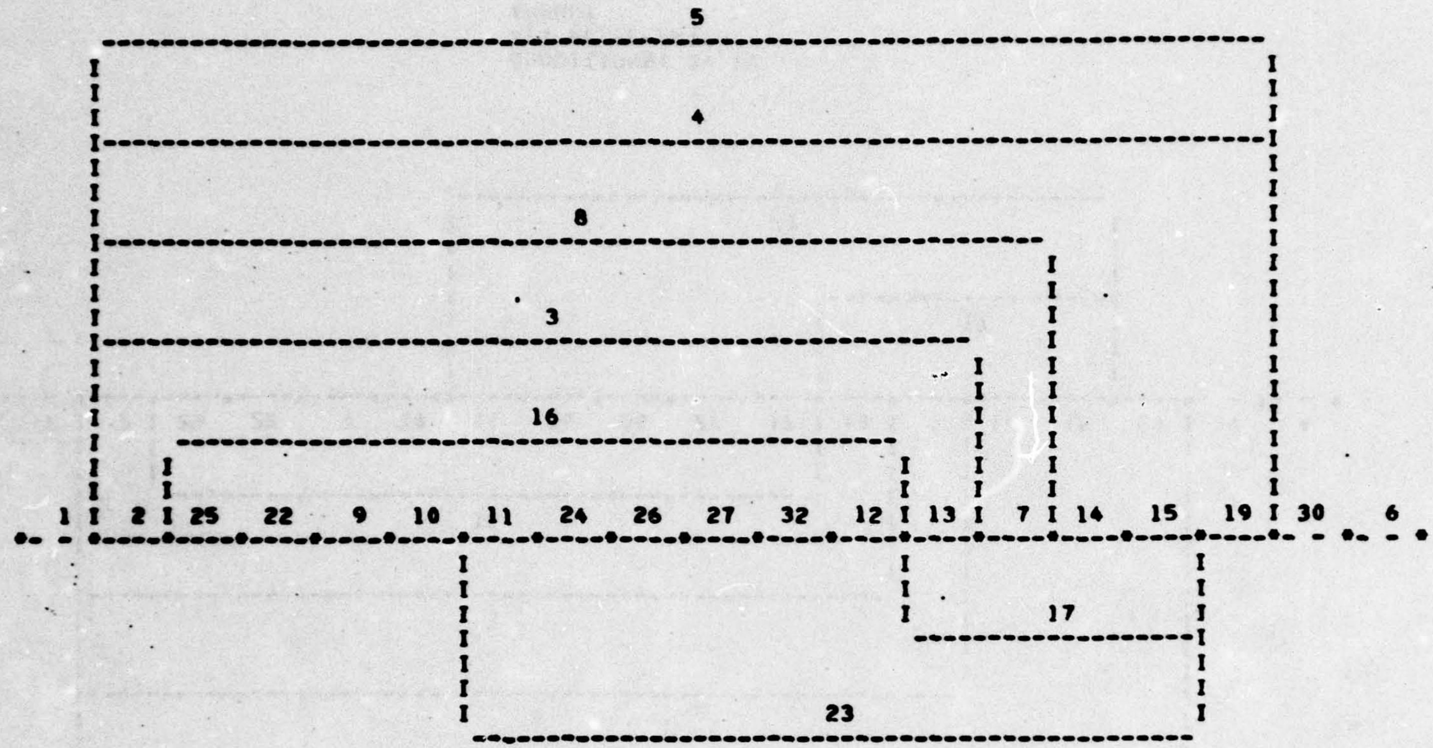
CONDITIONS: 3, 9
AE, ACCELERATED
AMOUNT
110000.



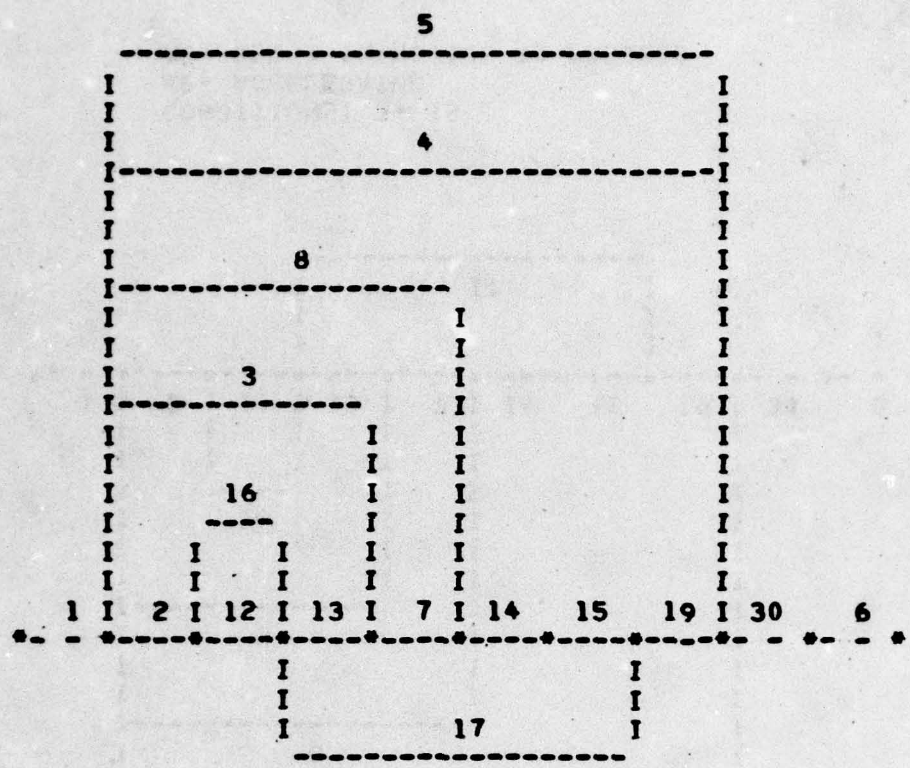
CONDITIONS: 3, 11
AE, ACCELERATED
AMOUNT
160000.



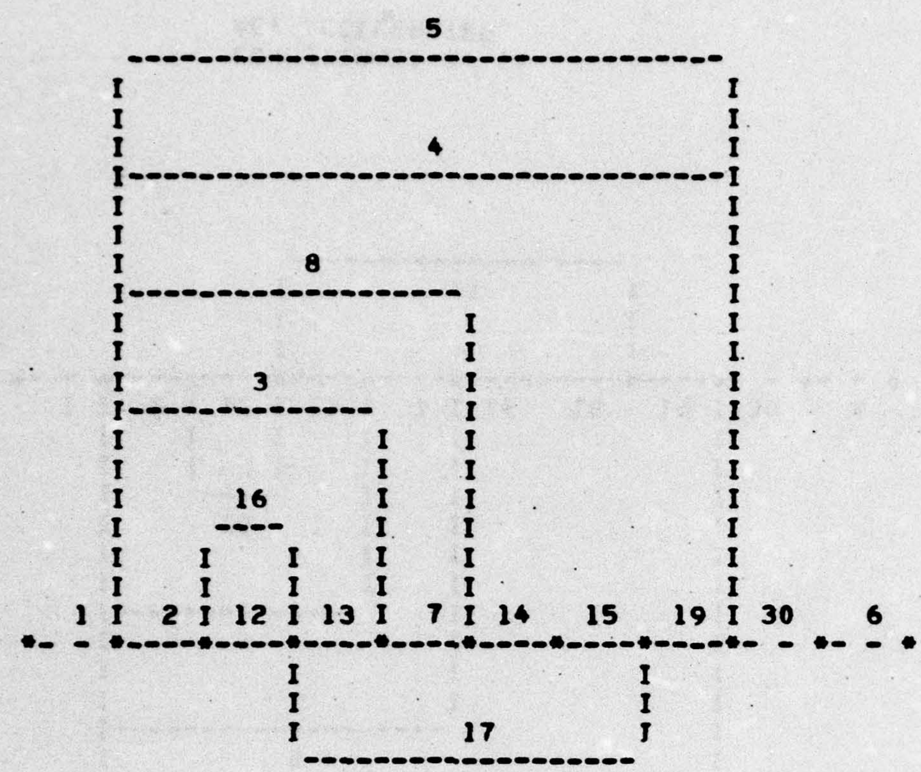
CONDITIONS: 3, 12
AE, ACCELERATED
AMOUNT
600000.



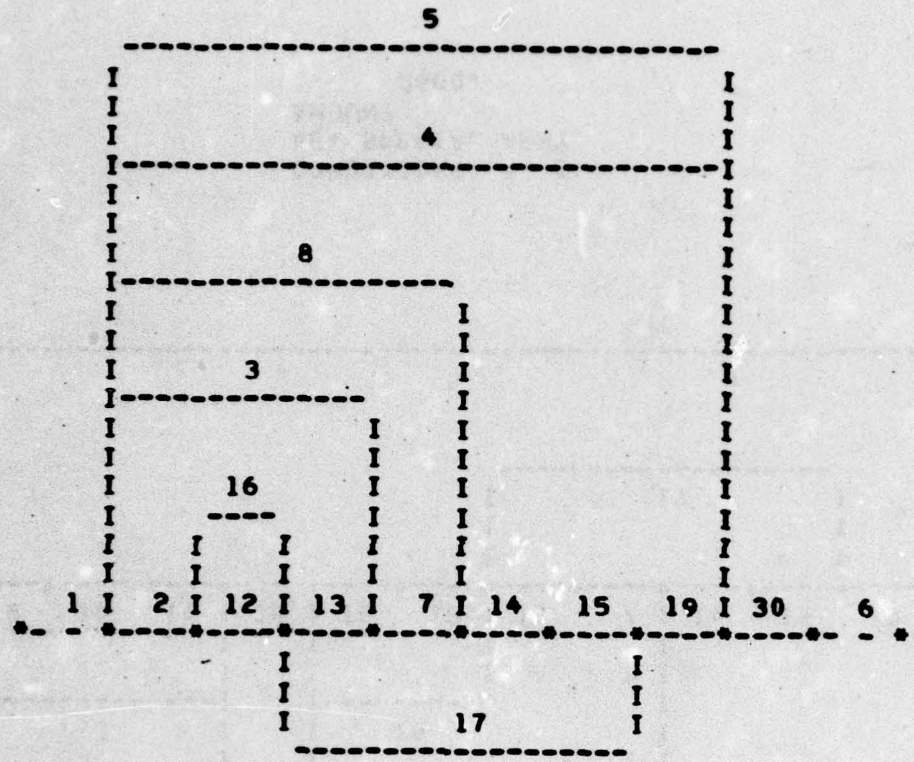
CONDITIONS: 3, 13
AE, ACCELERATED
AMOUNT
2000000.



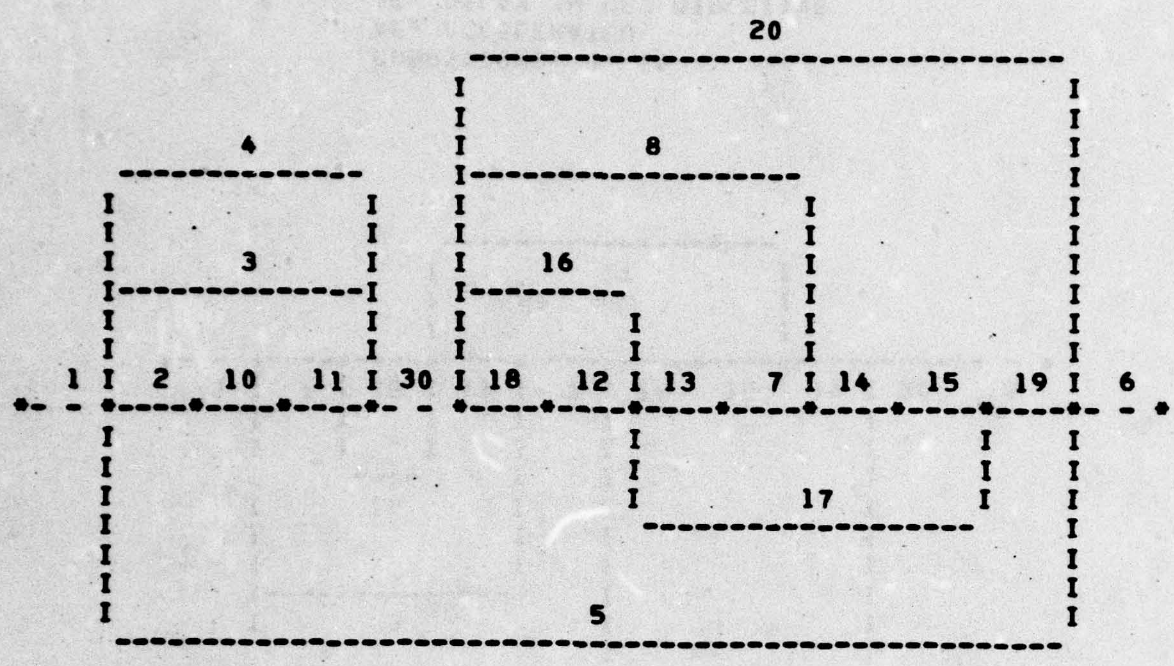
CONDITIONS: 3, 14
AE, ACCELERATED



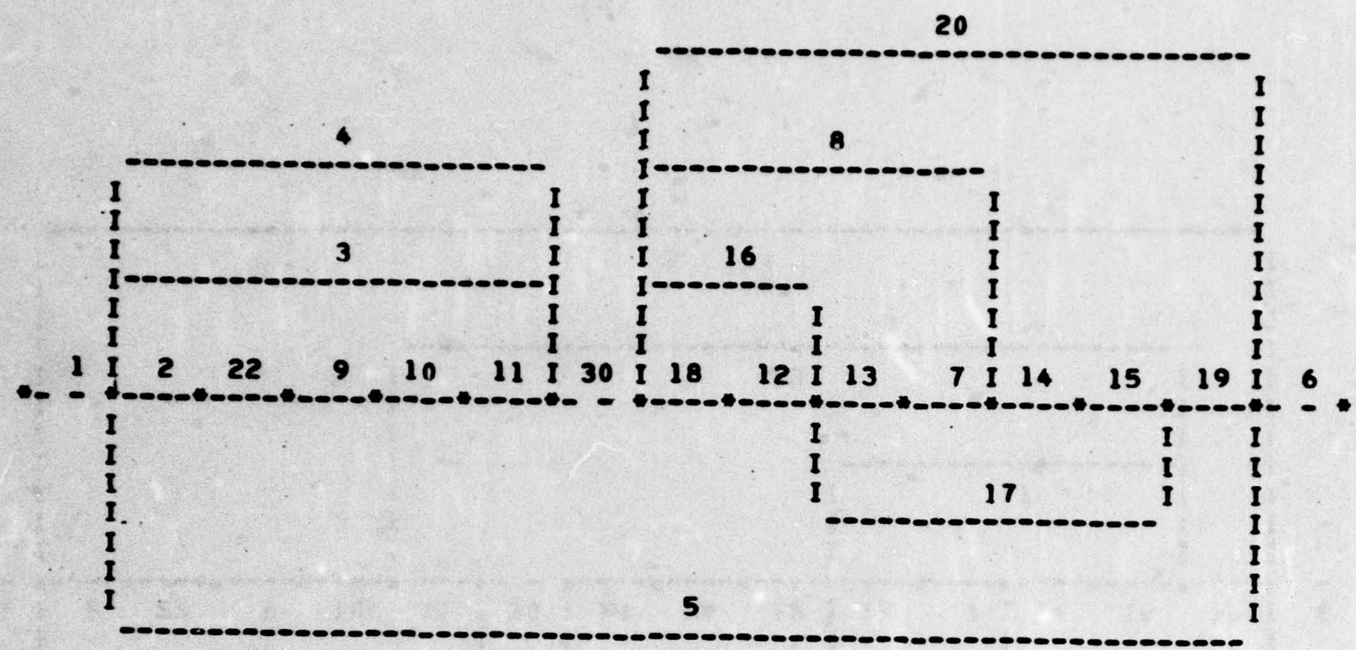
CONDITIONS: 3, 15
AE, ACCELERATED
AE, DELAY IN NOTICE TO PROCEED



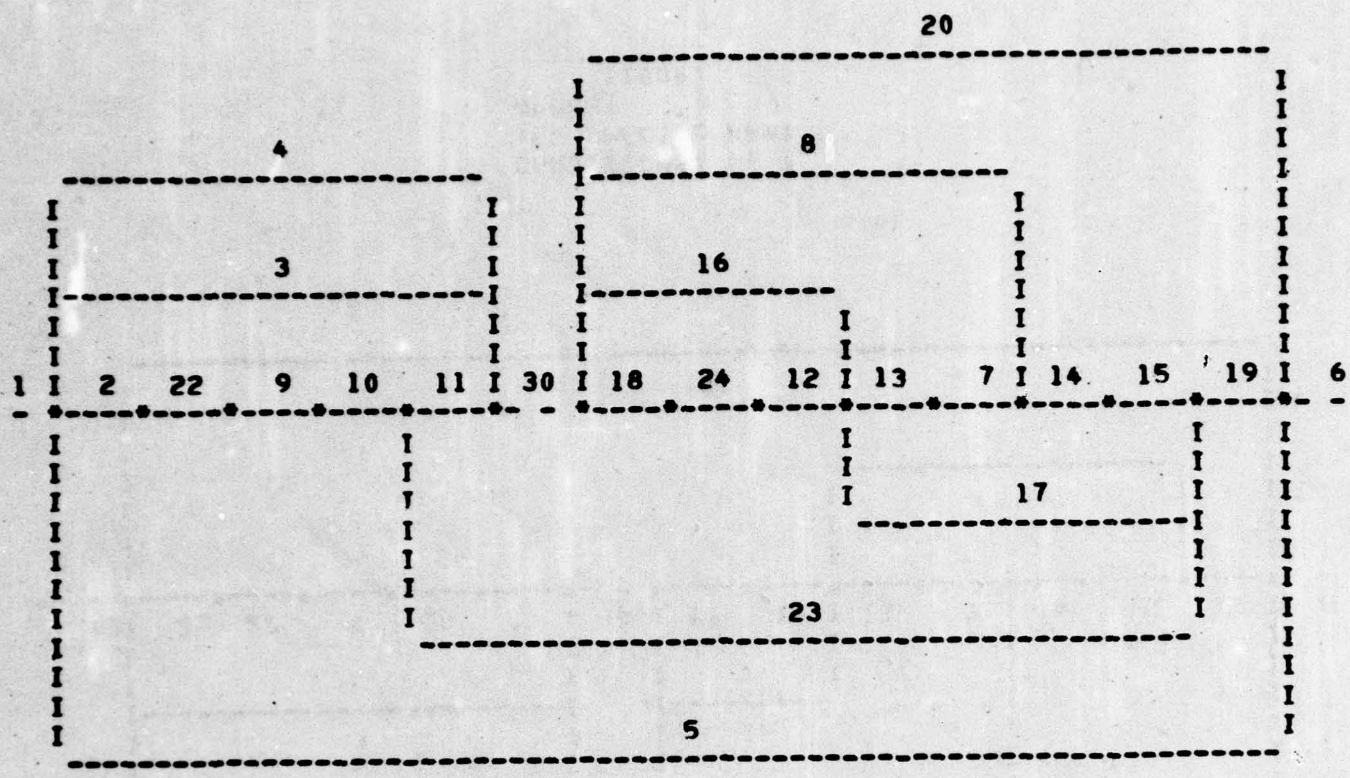
CONDITIONS: 3, 16
AE, ACCELERATED
AE, DELAY IN DES DIRECTIVE



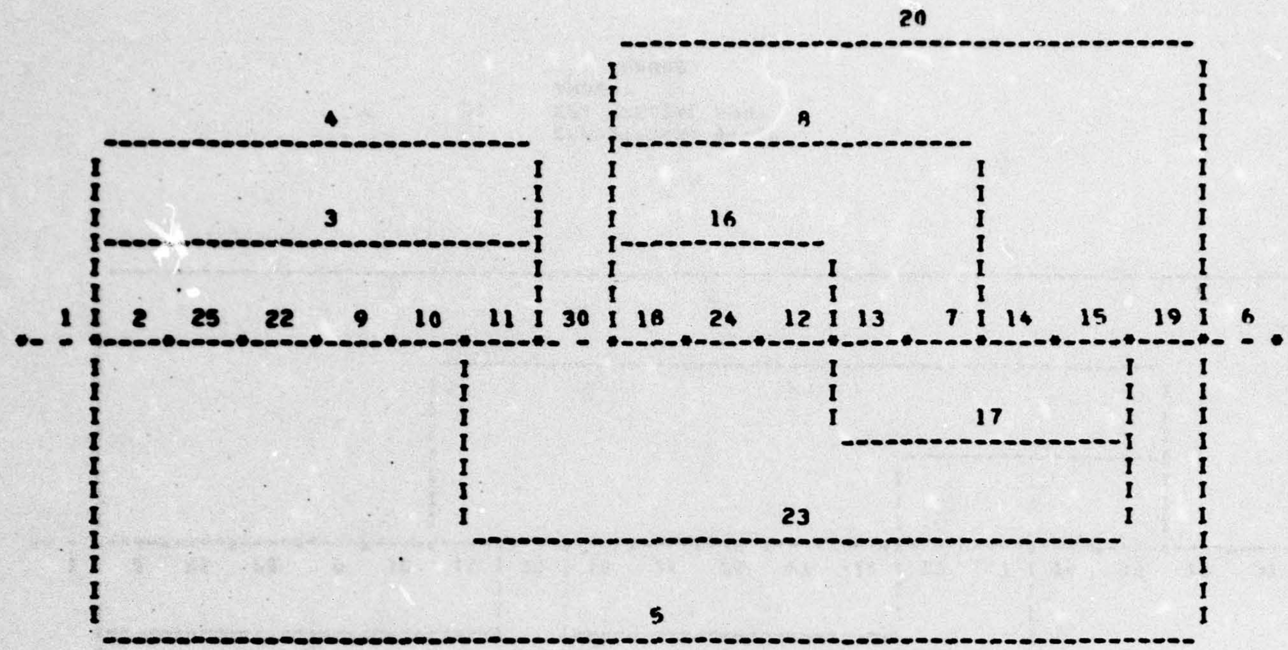
CONDITIONS: 4, 6
AE, SPECIAL ARMY
AMOUNT
2600.



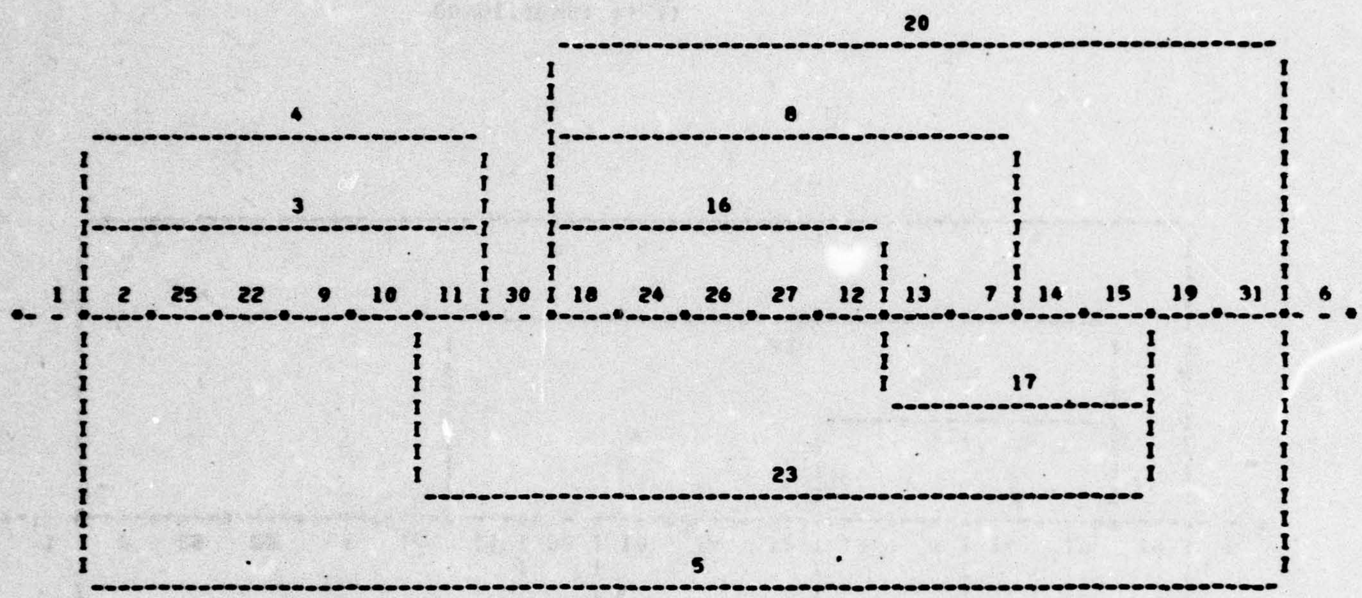
CONDITIONS: 4, 7
AE, SPECIAL ARMY
AMOUNT
11000.



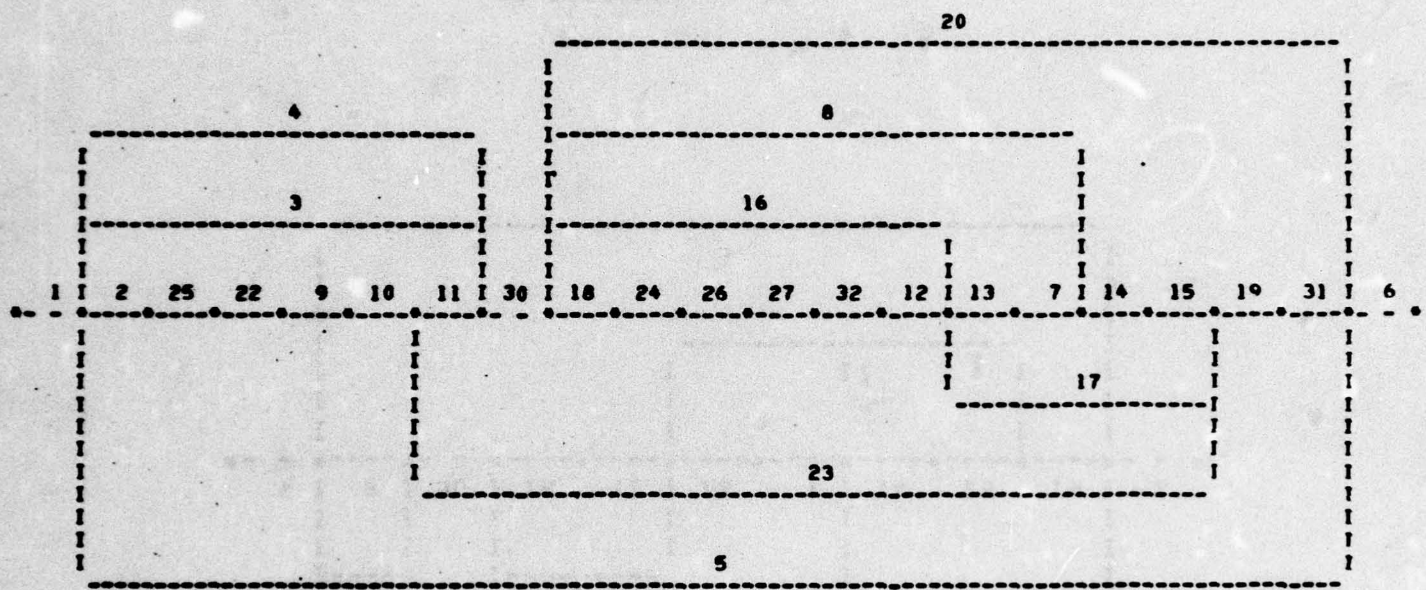
CONDITIONS: 4, 9
AE, SPECIAL ARMY
AMOUNT
110000.



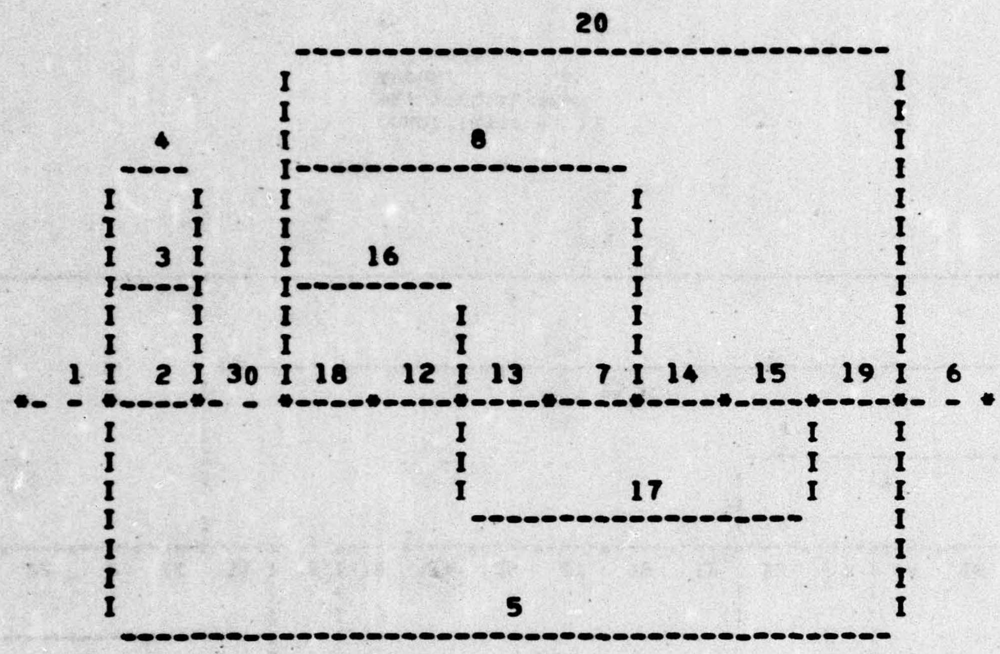
CONDITIONS: 4. 11
AE. SPECIAL ARMY
AMOUNT
160000.



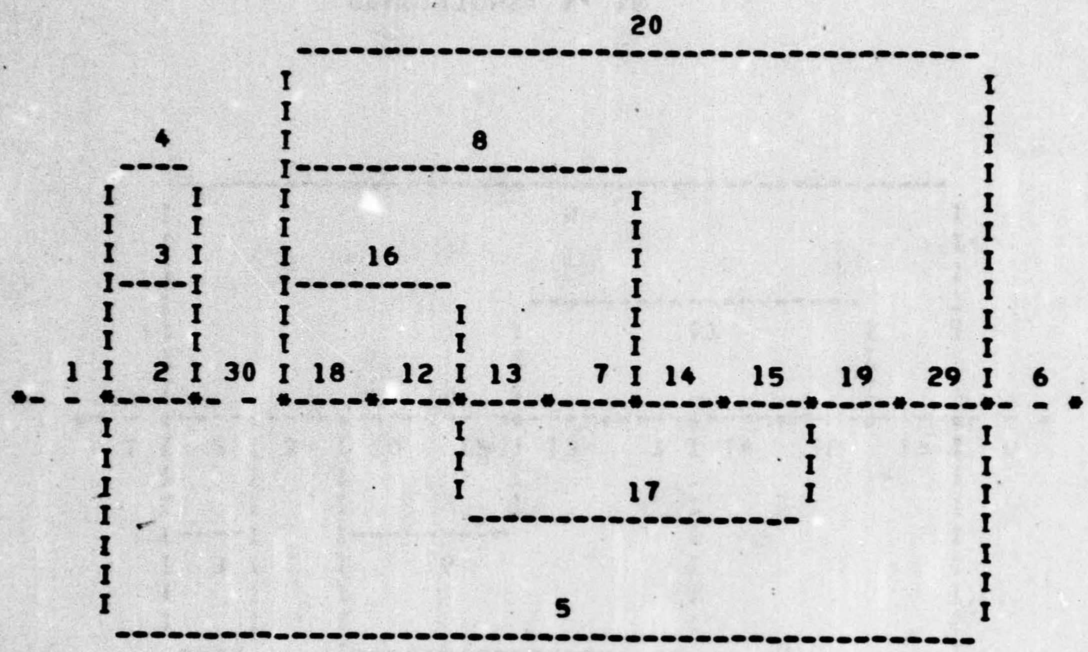
CONDITIONS: 4, 12
AE, SPECIAL ARMY
AMOUNT
600000.



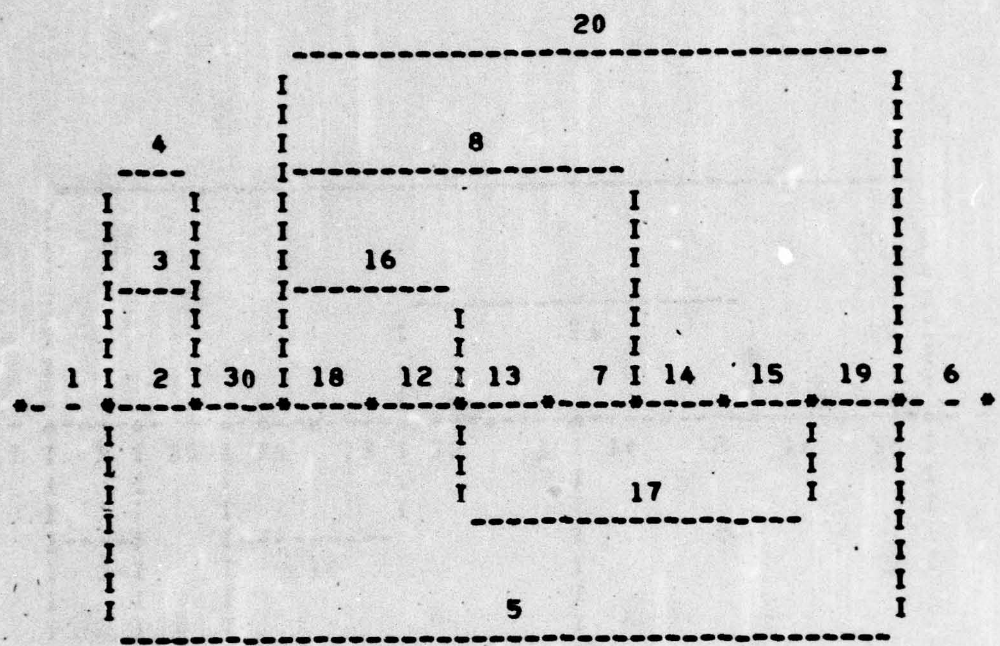
CONDITIONS: 4, 13
AE, SPECIAL ARMY
AMOUNT
2000000.



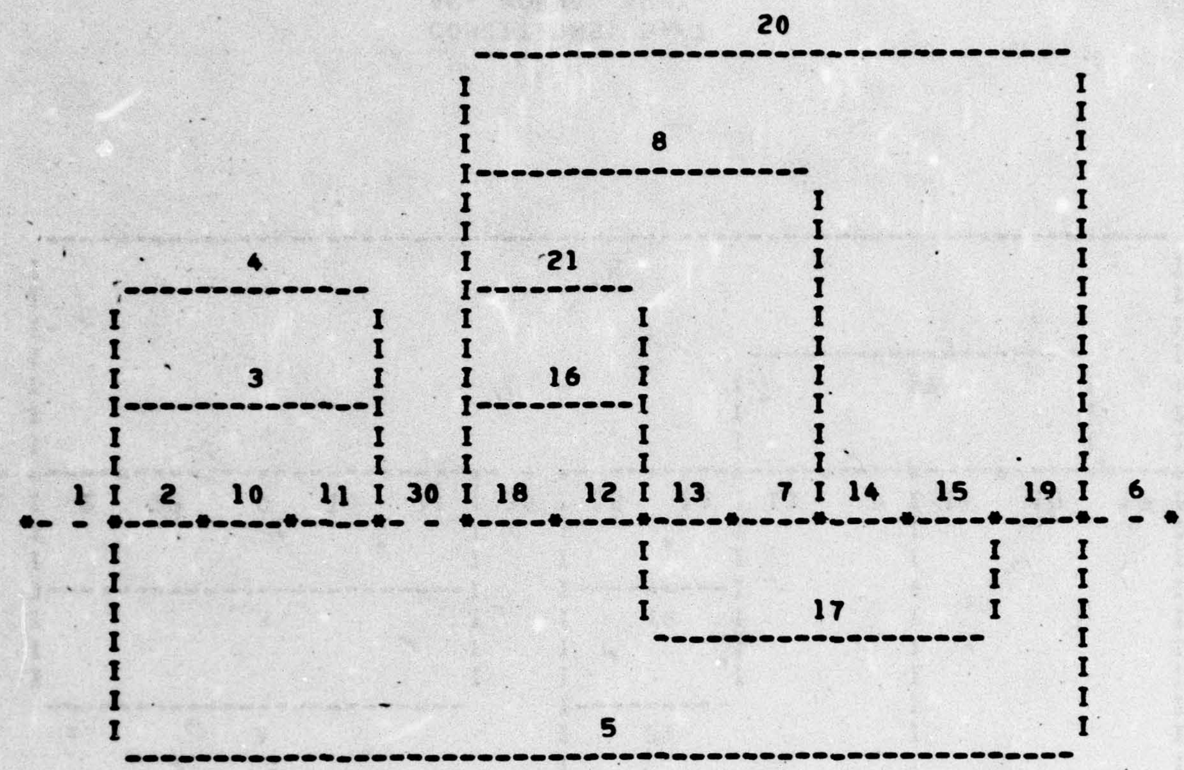
CONDITIONS: 4, 14
AE, SPECIAL ARMY



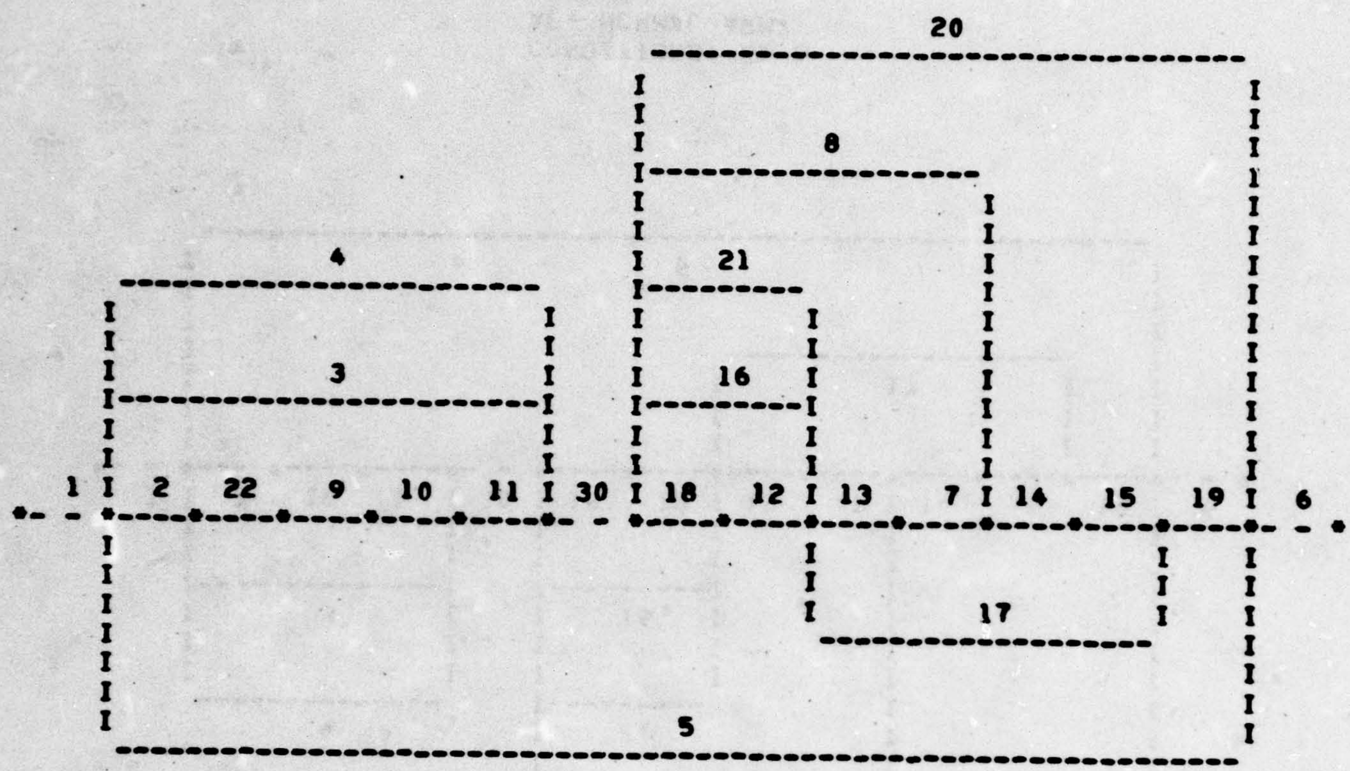
CONDITIONS: 4, 15
AE, SPECIAL ARMY
AE, DELAY IN NOTICE TO PROCEED



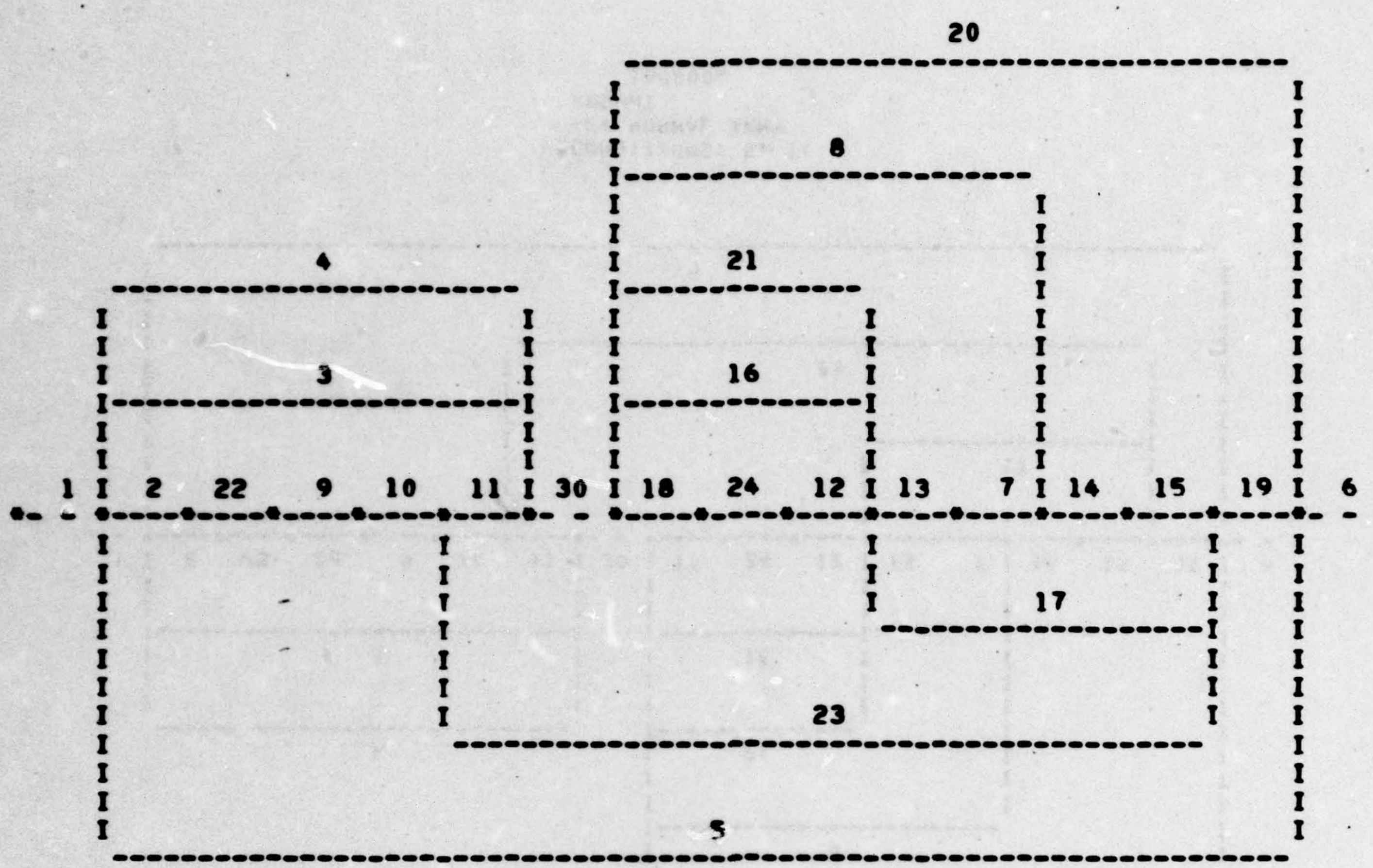
CONDITIONS: 4, 16
AE, SPECIAL ARMY
AE. DELAY IN DES DIRECTIVE



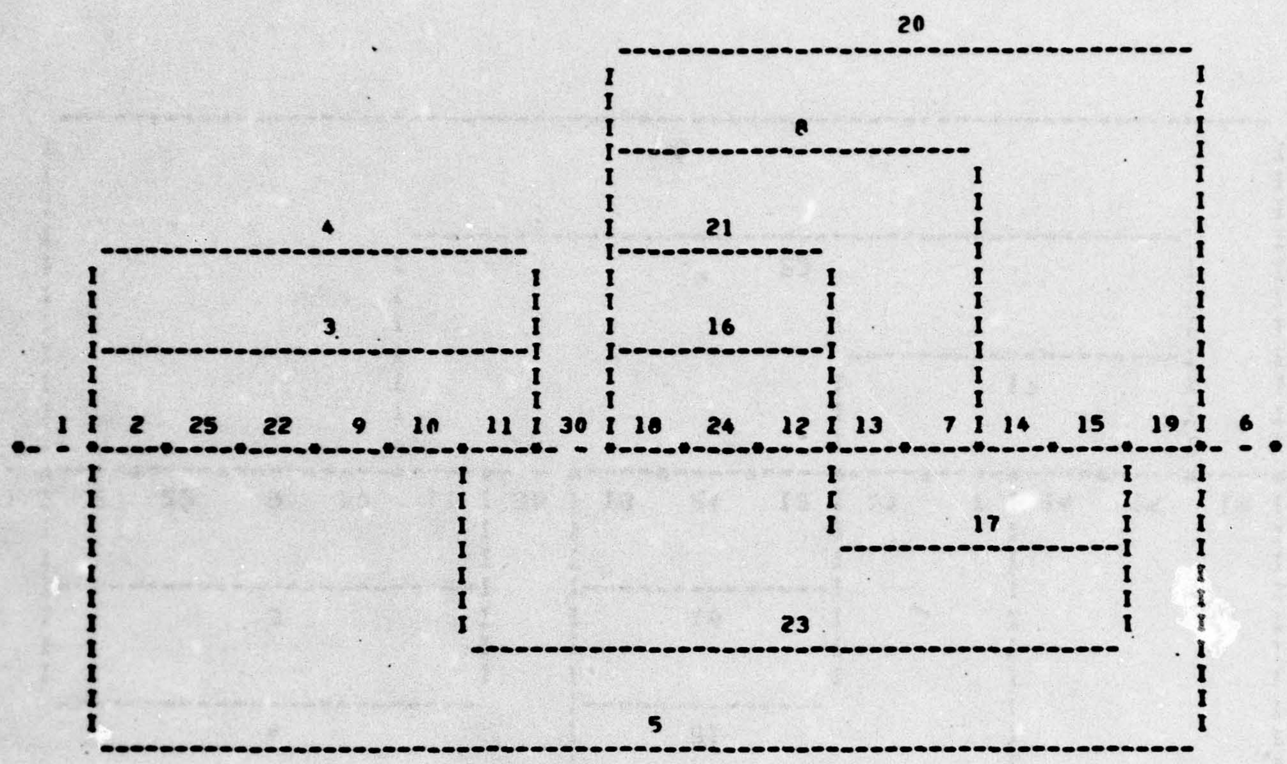
CONDITIONS: 5, 6
AE, NORMAL ARMY
AMOUNT
2600.



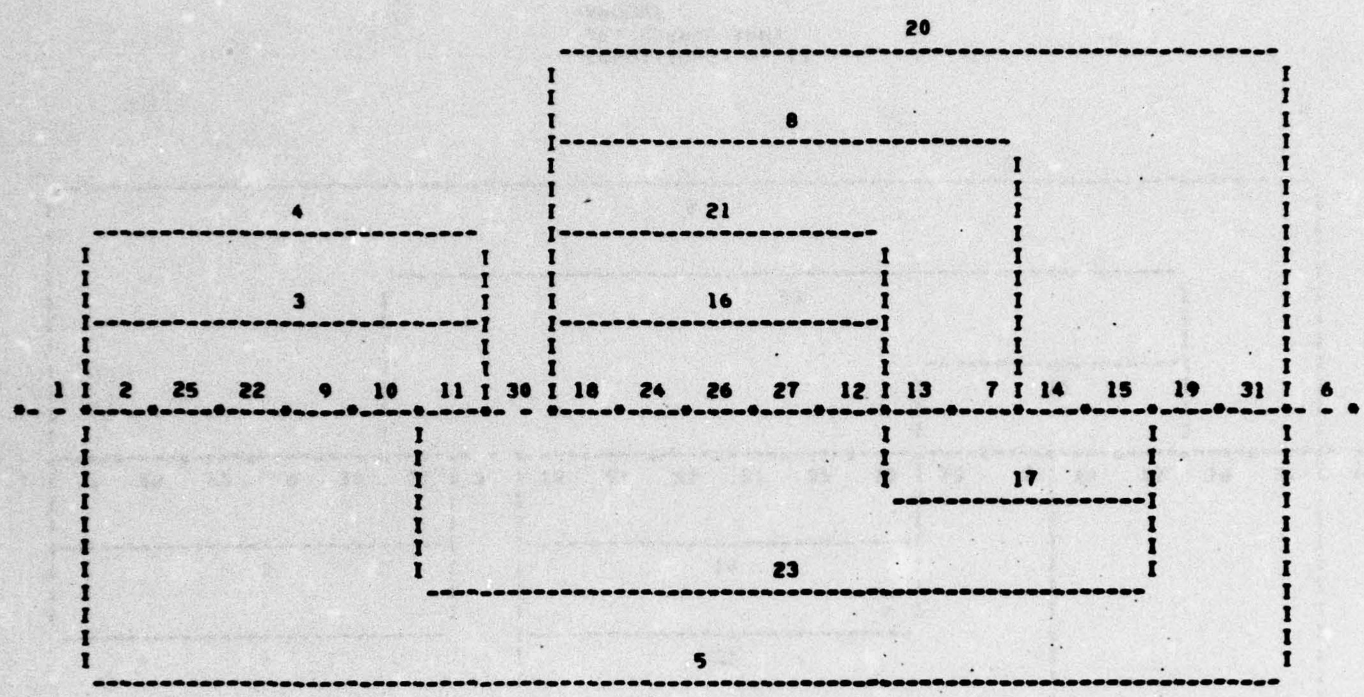
CONDITIONS: 5, 7
AE, NORMAL ARMY
AMOUNT
11000.



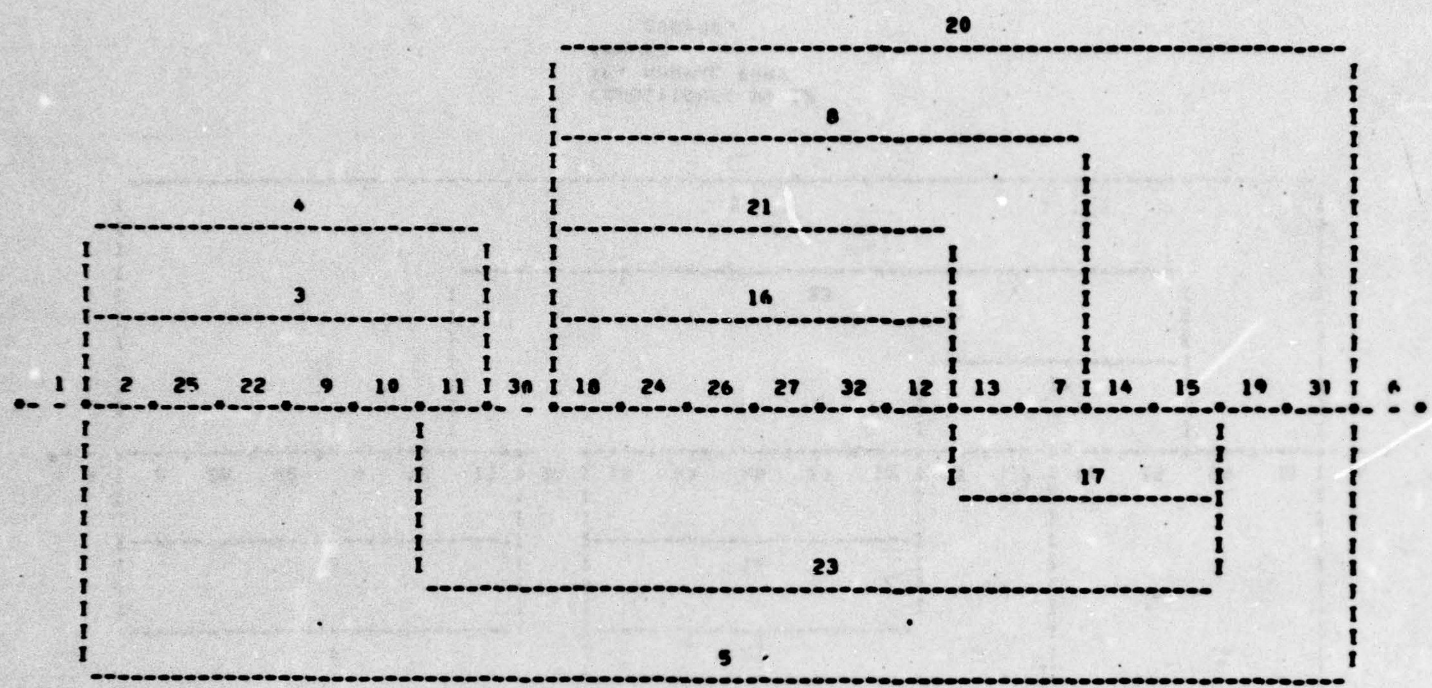
CONDITIONS: 5, 9
AE, NORMAL ARMY
AMOUNT
110000.



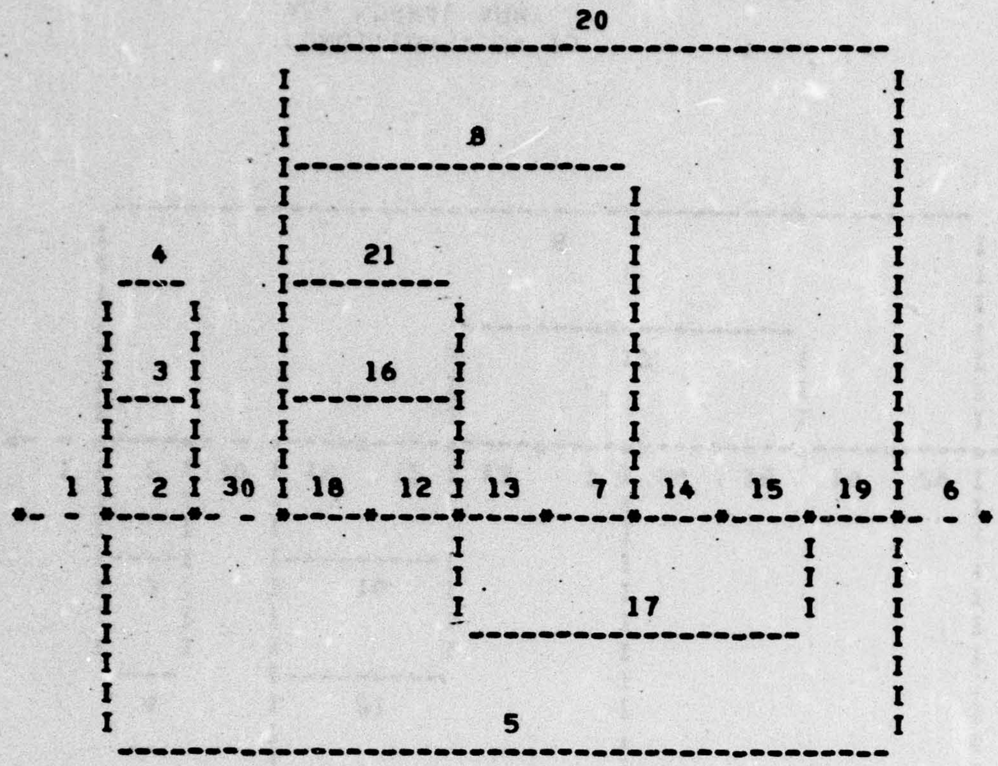
CONDITIONS: 5, 11
AE, NORMAL ARMY
AMOUNT
160000.



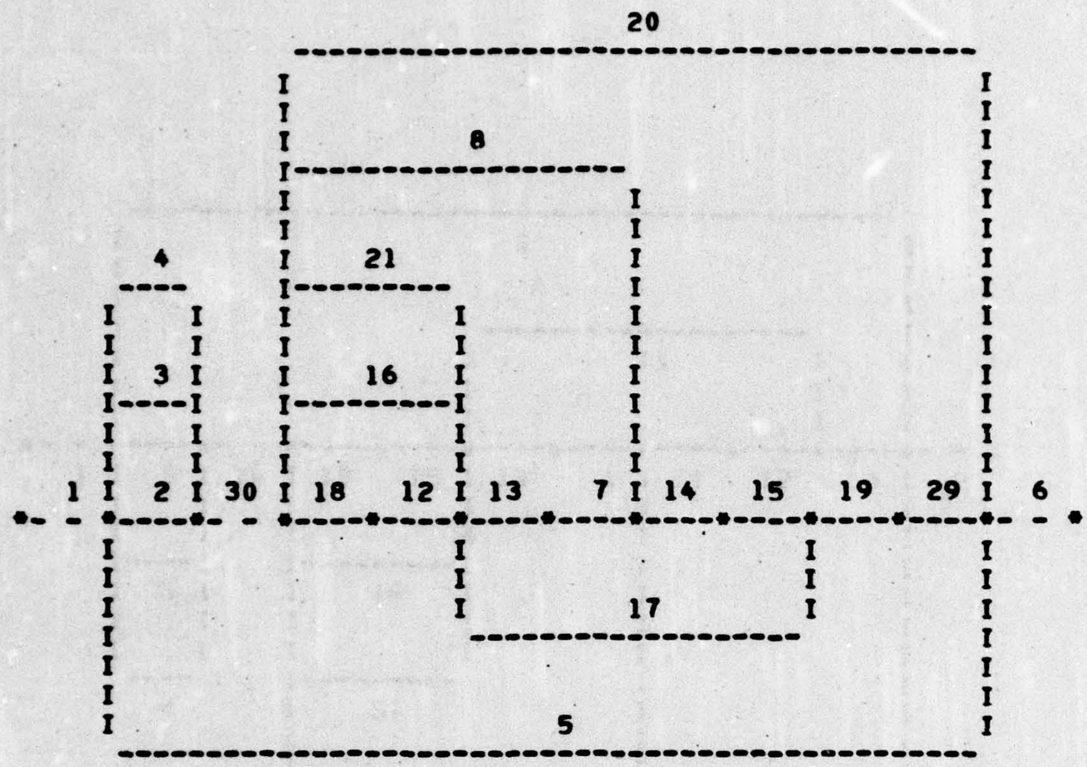
CONDITIONS: 5, 12
AE, NORMAL ARMY
AMOUNT
600000.



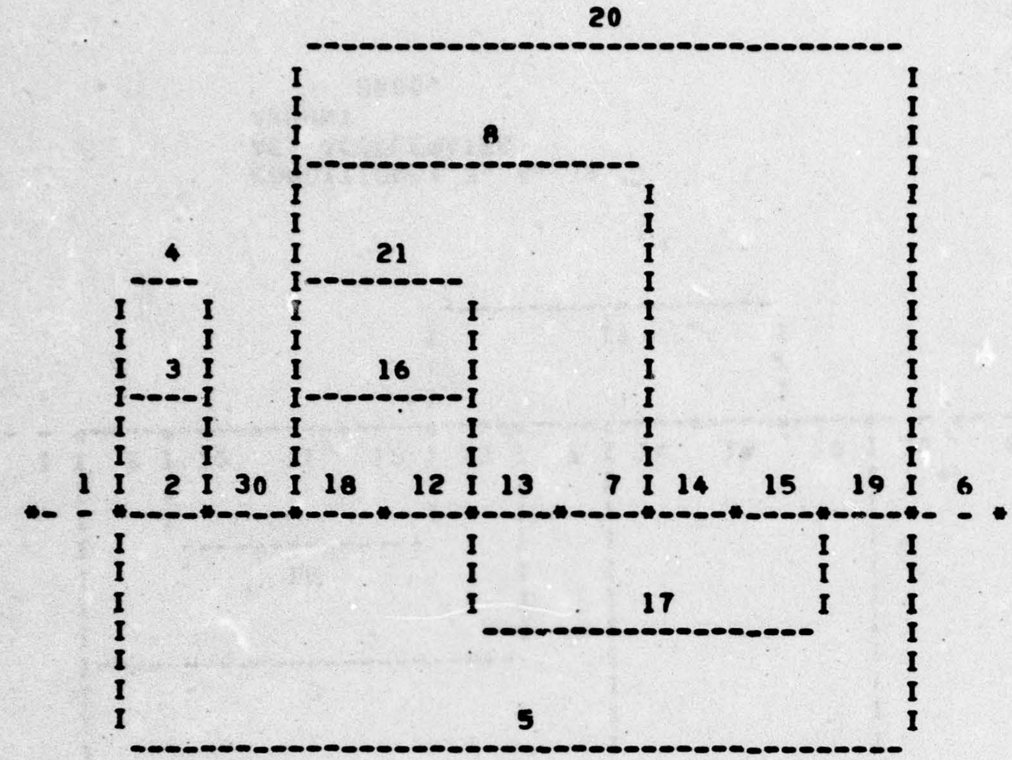
CONDITIONS: 5, 13
AE, NORMAL ARMY
AMOUNT
2000000.



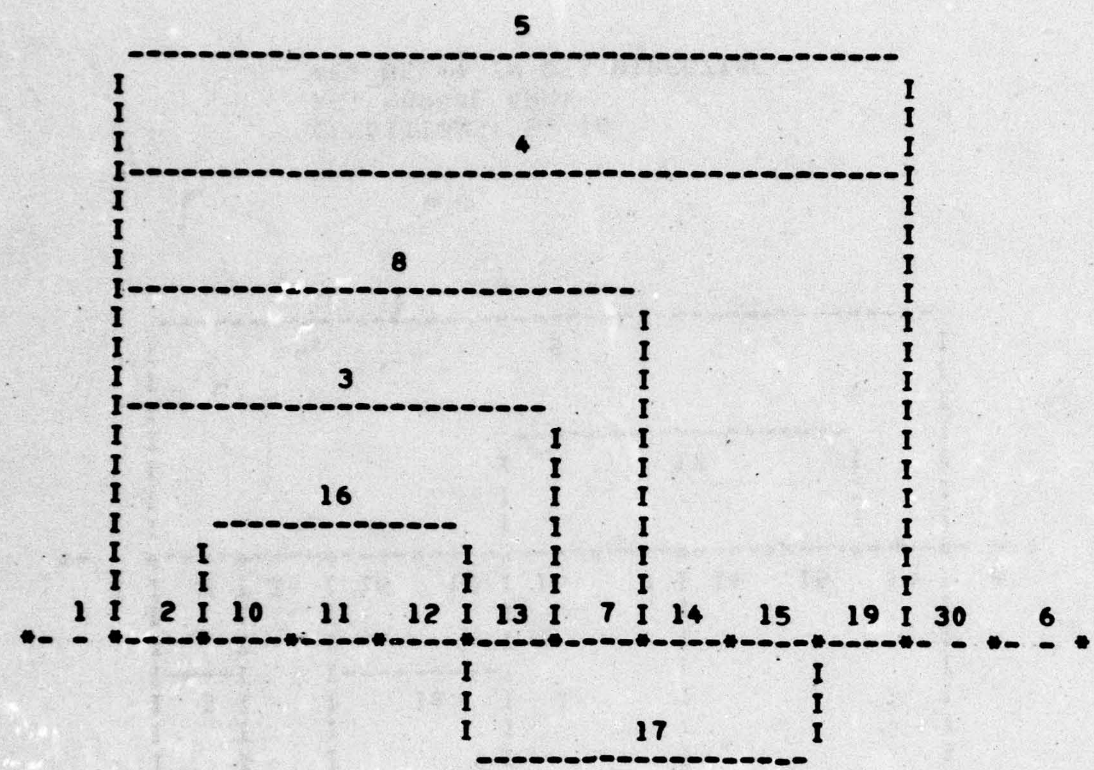
CONDITIONS: 5, 14
AE, NORMAL ARMY



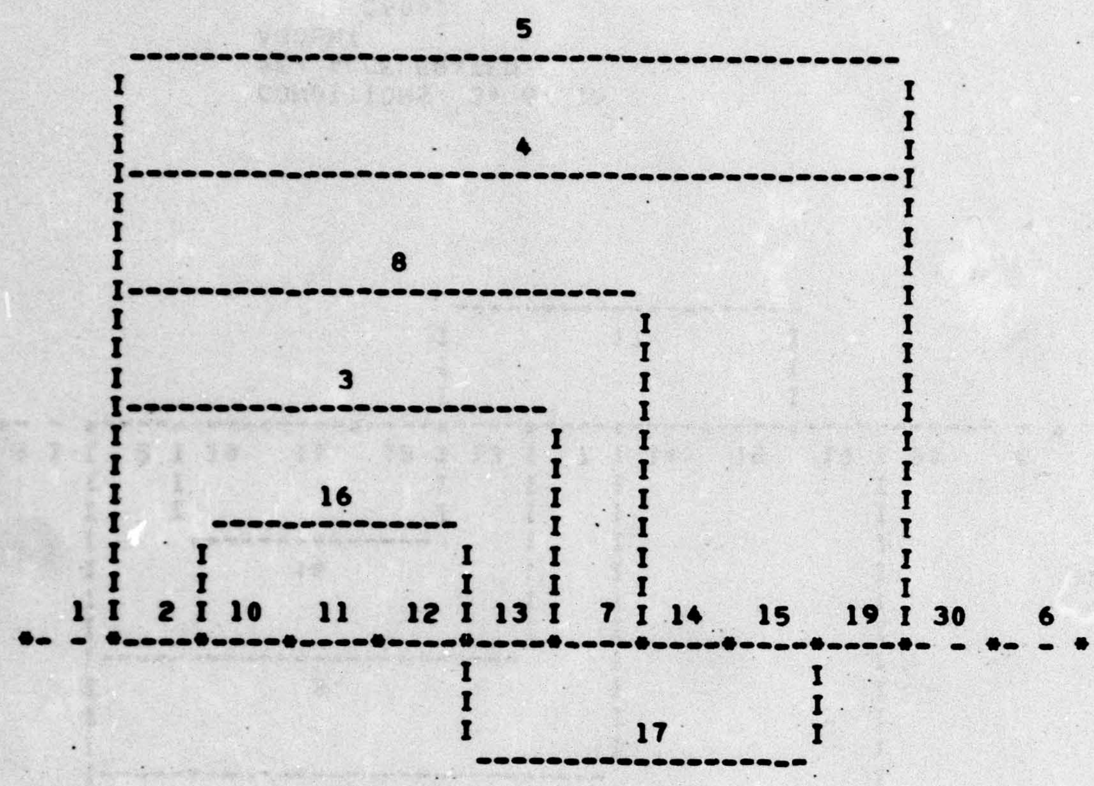
CONDITIONS: 5, 15
AE, NORMAL ARMY
AE, DELAY IN NOTICE TO PROCEED



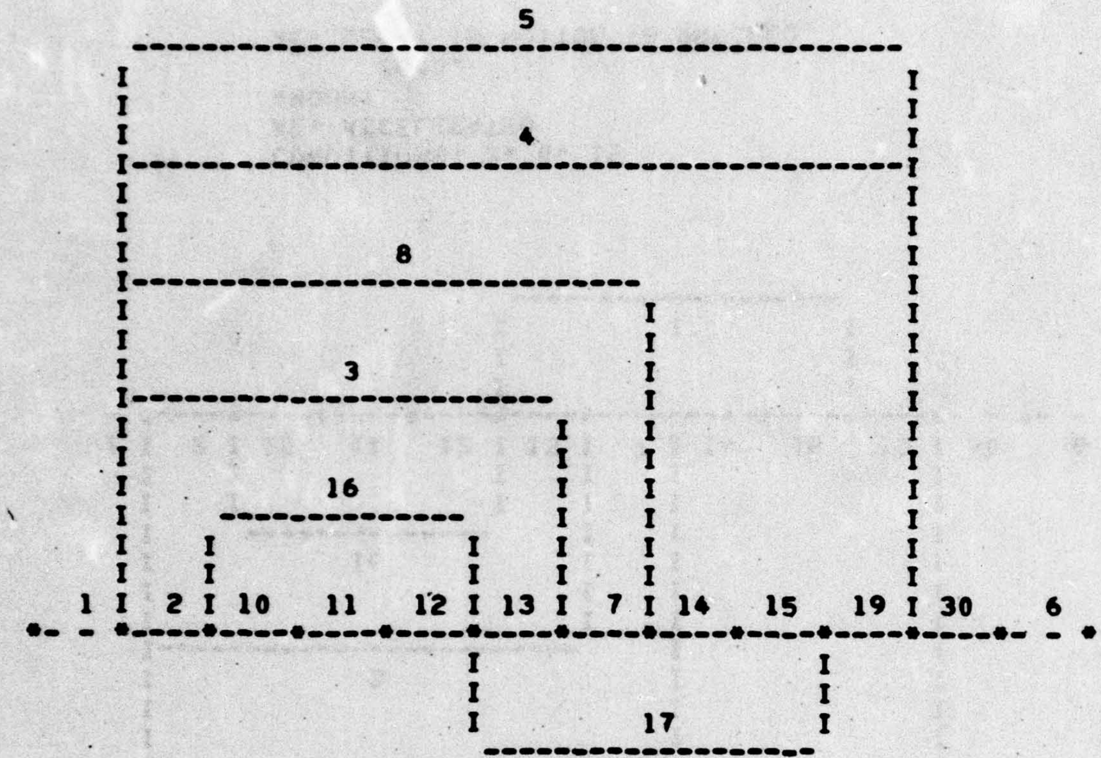
CONDITIONS: 5, 16
AE, NORMAL ARMY
AE, DELAY IN DES DIRECTIVE



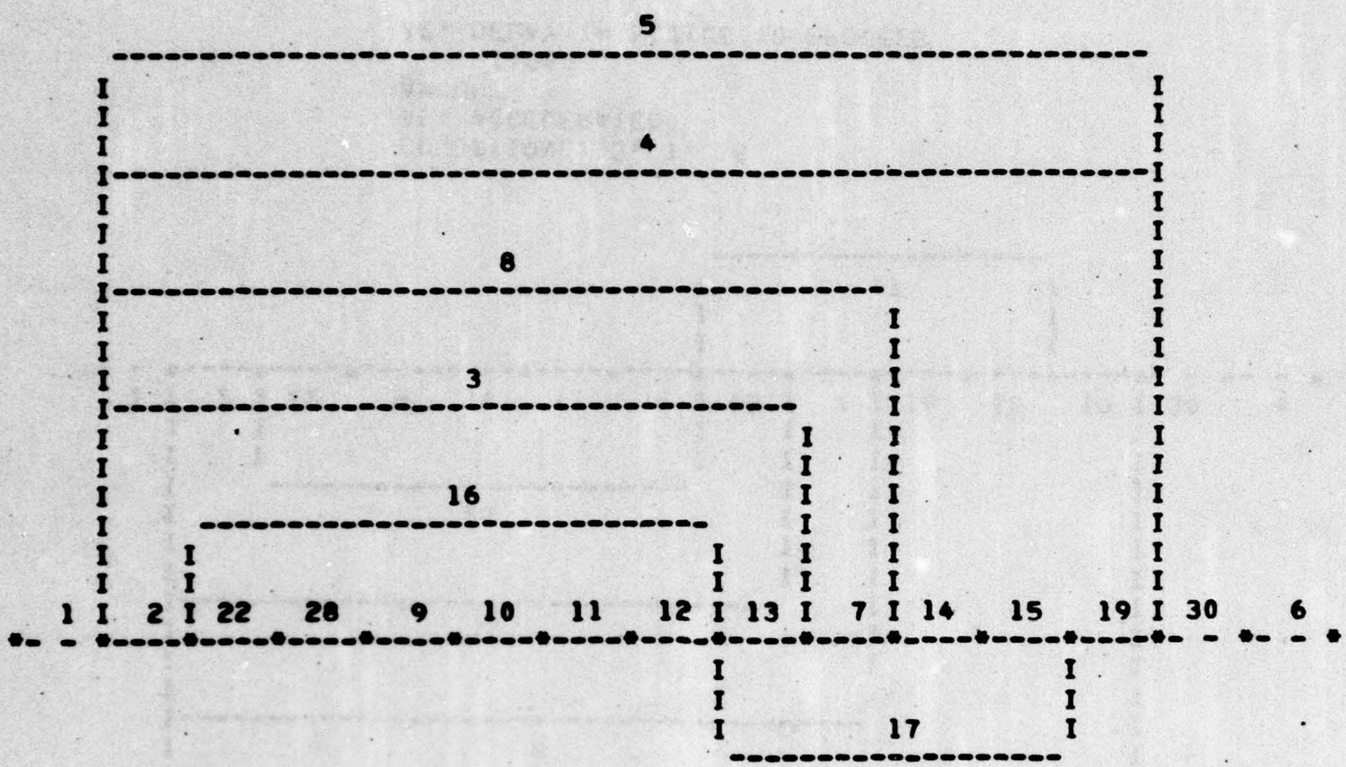
CONDITIONS: 3, 6, 14
AE, ACCELERATED
AMOUNT
2600.



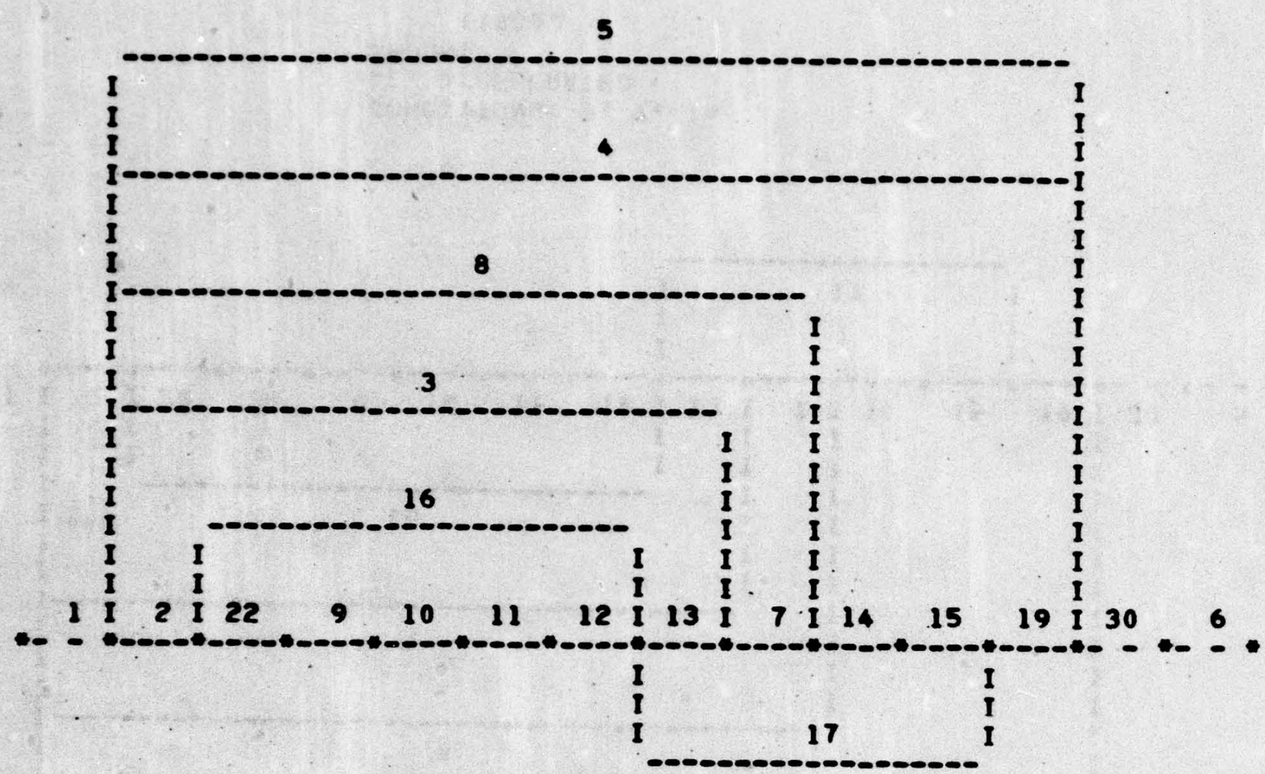
CONDITIONS: 3, 6, 15
AE, ACCELERATED
AMOUNT
2600.
AE, DELAY IN NOTICE TO PROCEED



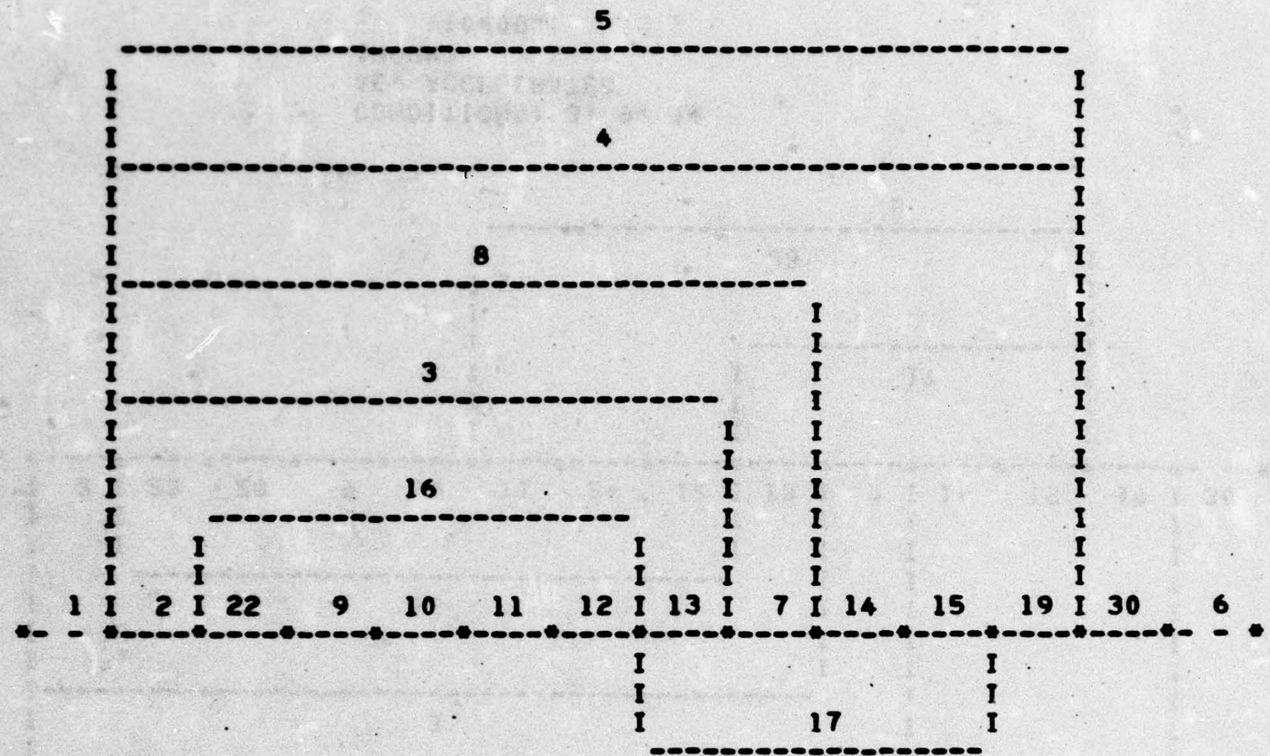
CONDITIONS: 3, 6, 16
AE, ACCELERATED
AMOUNT
2600.
AE, DELAY IN DES DIRECTIVE



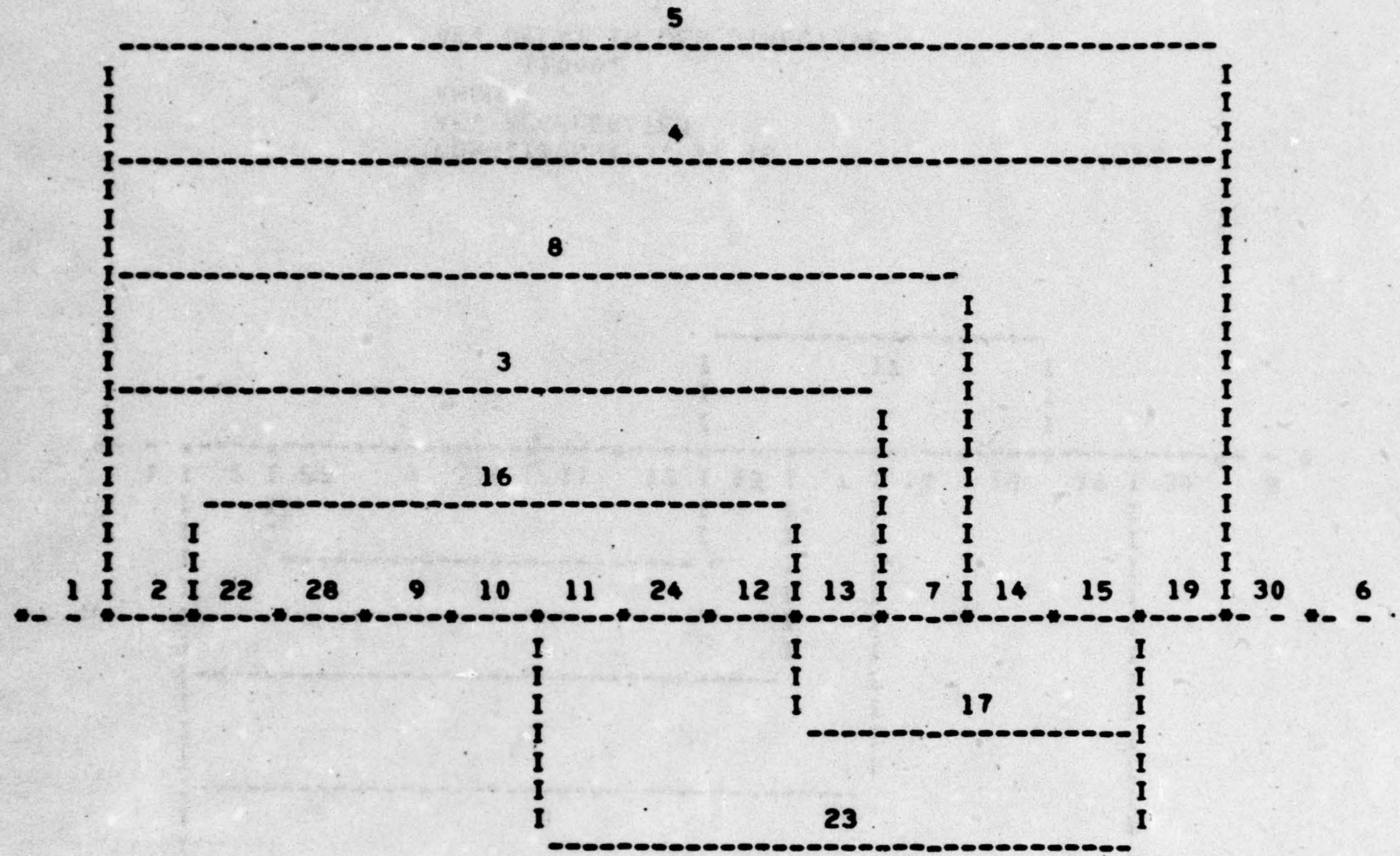
CONDITIONS: 3, 7, 14
AE, ACCELERATED
AMOUNT
11000.



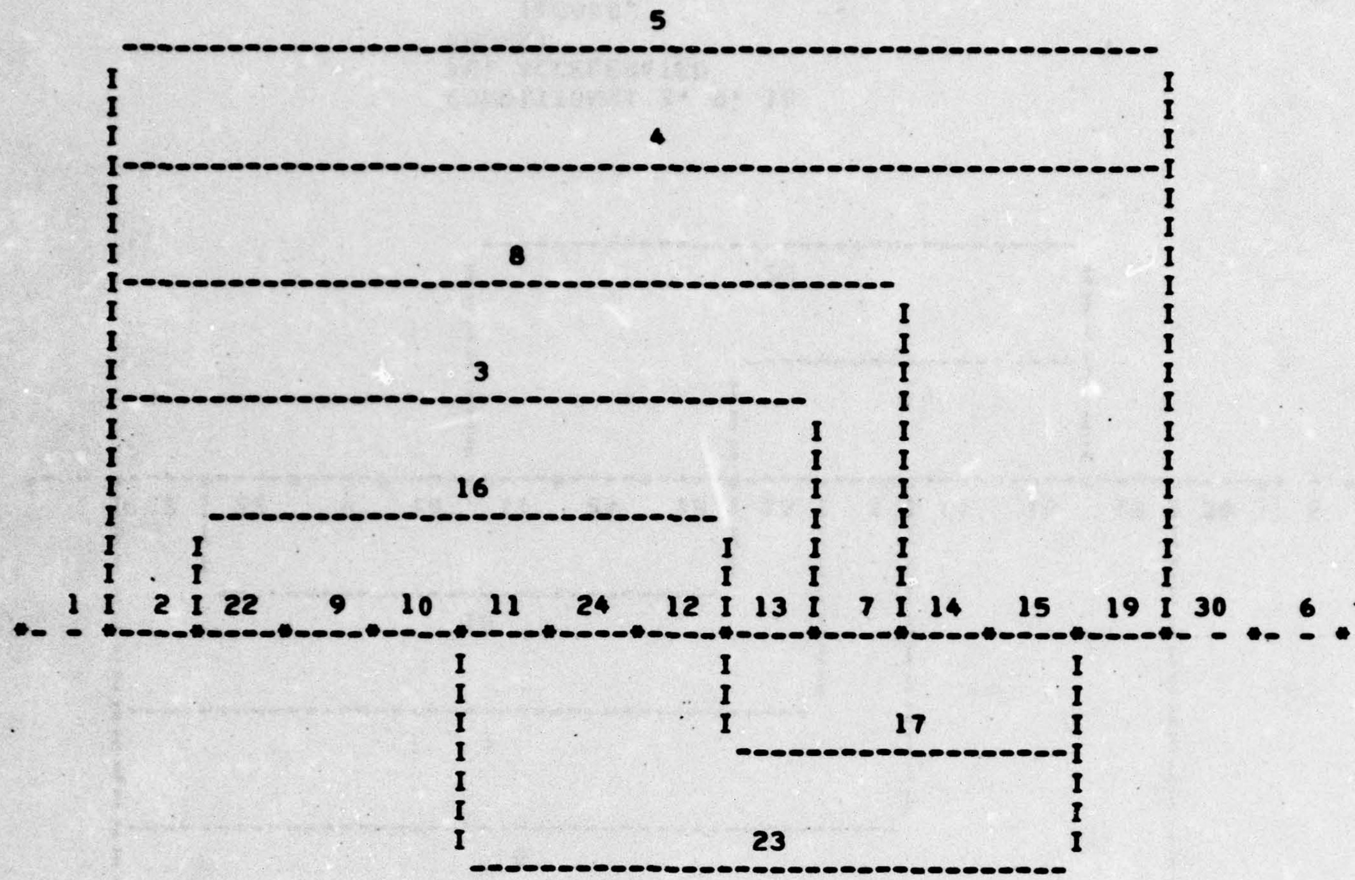
CONDITIONS: 3, 7, 15
AE, ACCELERATED
AMOUNT
11000.
AE, DELAY IN NOTICE TO PROCEED



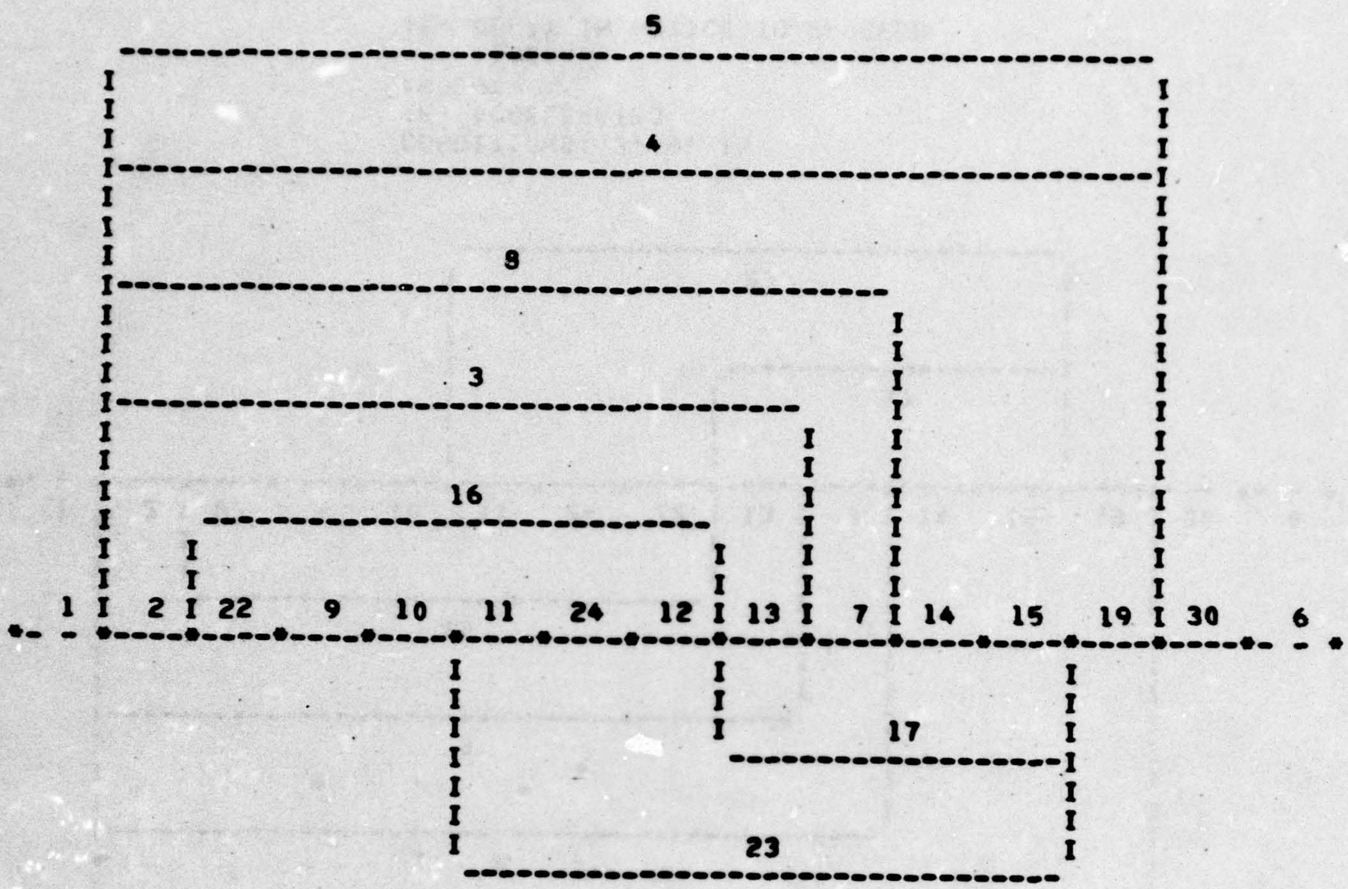
CONDITIONS: 3, 7, 16
AE, ACCELERATED
AMOUNT
11000.
AE, DELAY IN DES DIRECTIVE



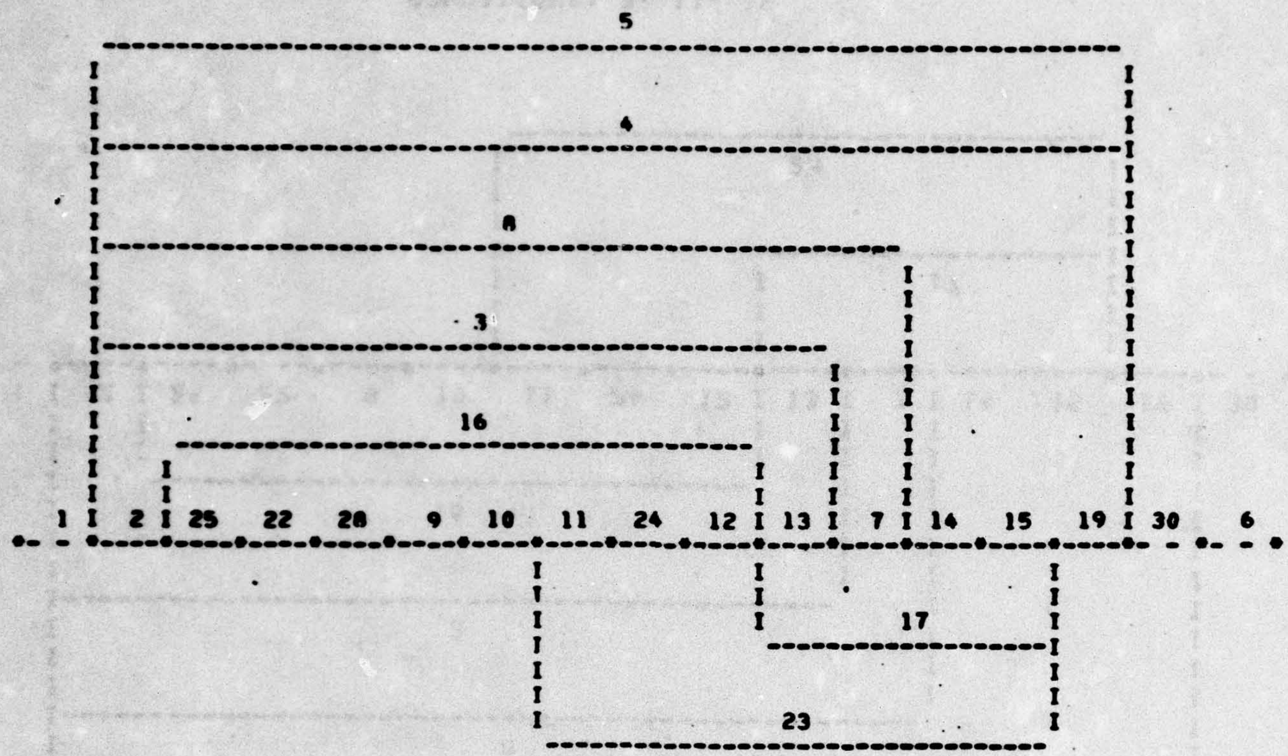
CONDITIONS: 3, 9, 14
AE, ACCELERATED
AMOUNT
110000.



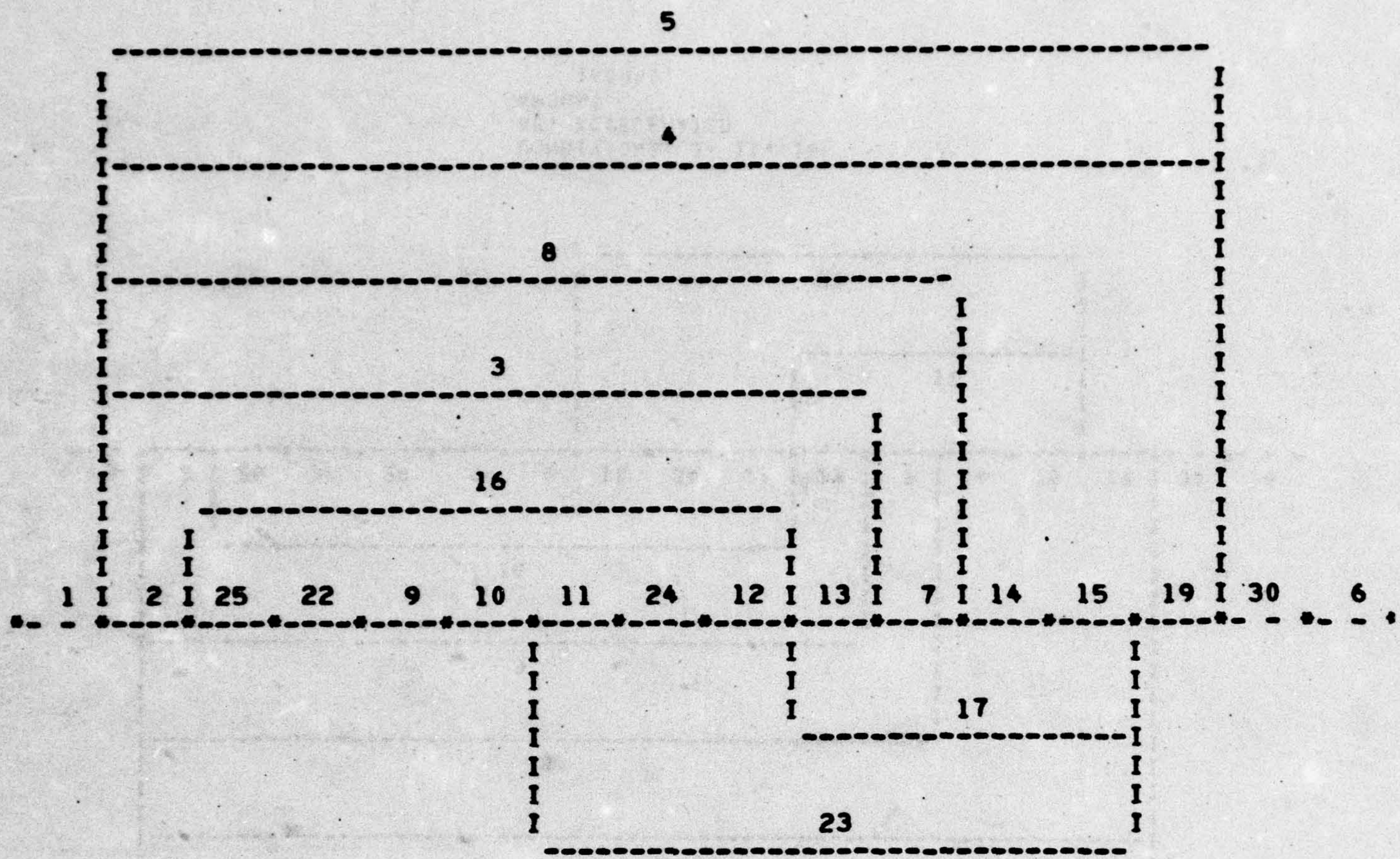
CONDITIONS: 3, 9, 15
AE, ACCELERATED
AMOUNT
110000.
AE, DELAY IN NOTICE TO PROCEED



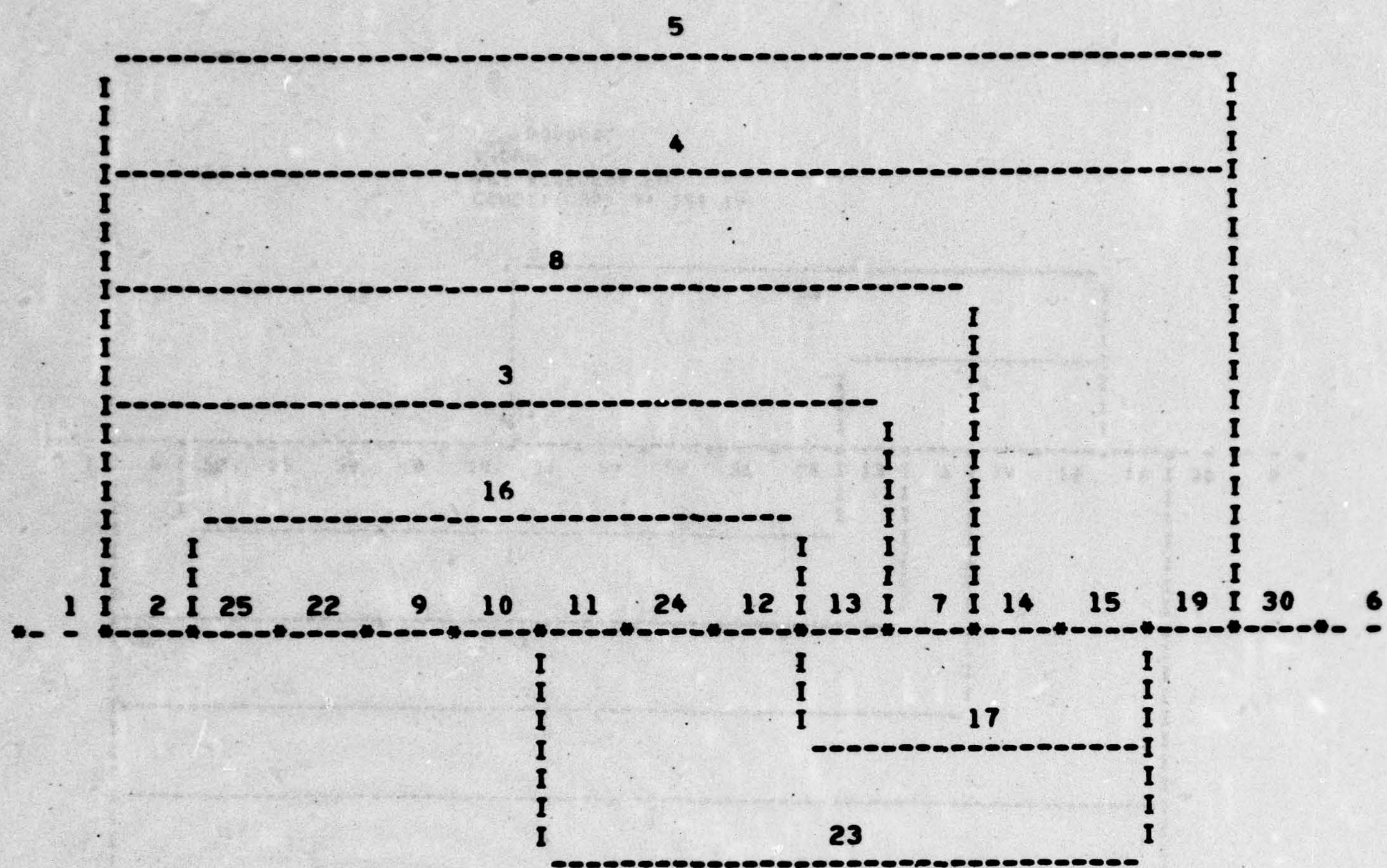
CONDITIONS: 3, 9, 16
AE, ACCELERATED
AMOUNT
110000.
AE, DELAY IN DES DIRECTIVE



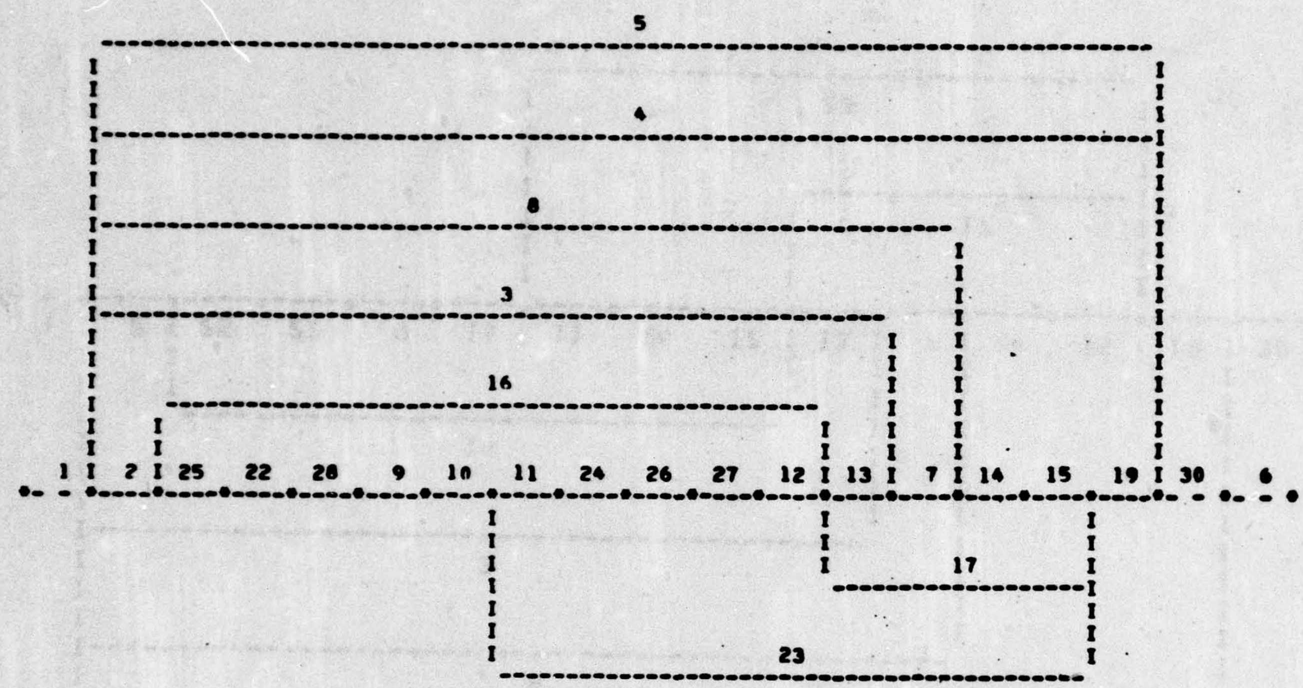
CONDITIONS: 3, 11, 14
AE, ACCELERATED
AMOUNT
160000.



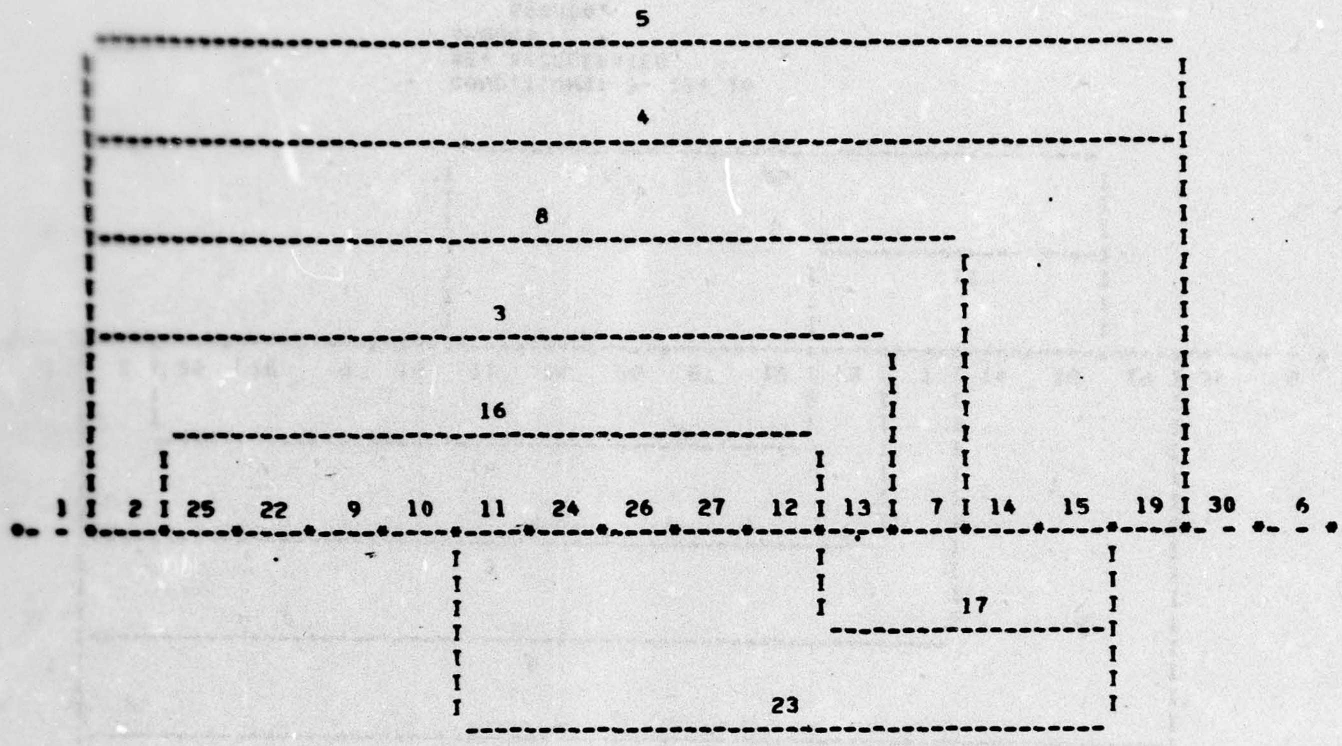
CONDITIONS: 3, 11, 15
AE, ACCELERATED
AMOUNT
160000.
AE, DELAY IN NOTICE TO PROCEED



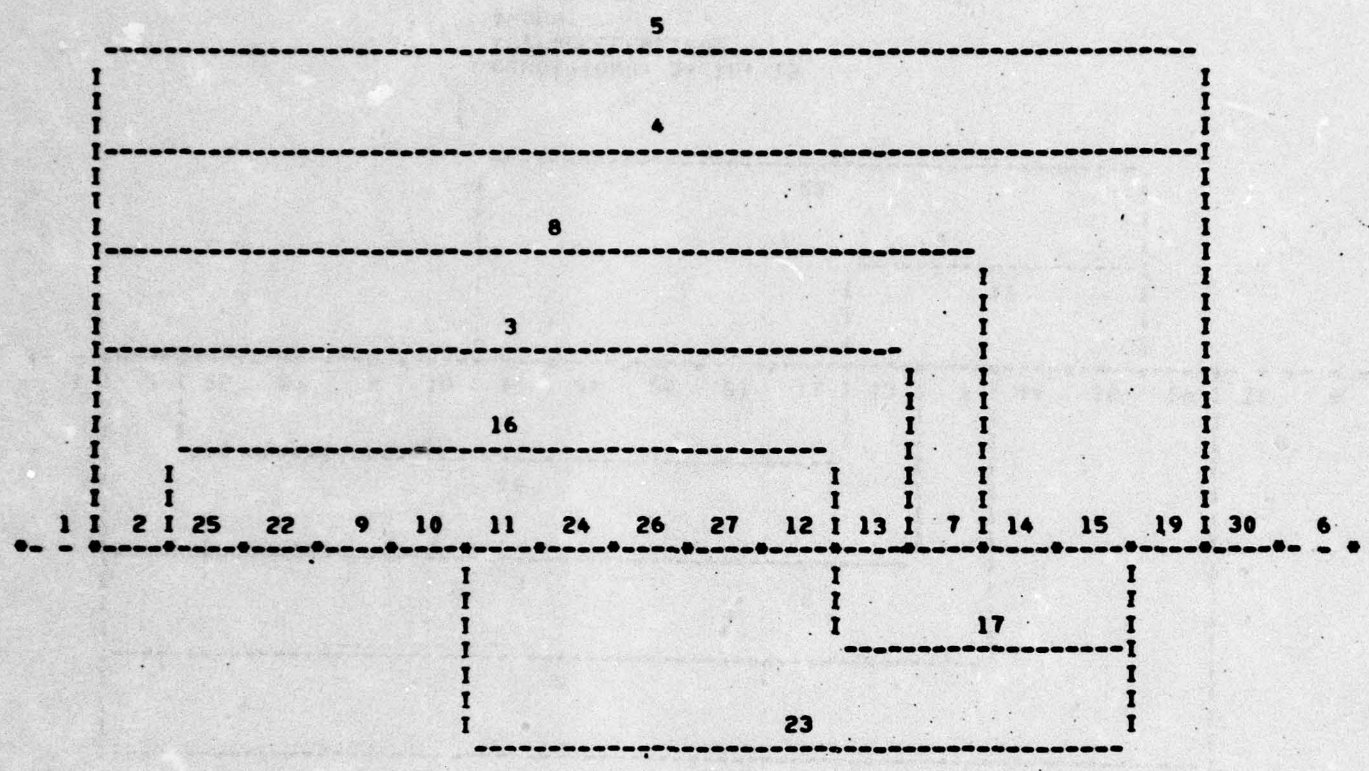
CONDITIONS: 3, 11, 16
AE, ACCELERATED
AMOUNT
160000.
AE, DELAY IN DES DIRECTIVE



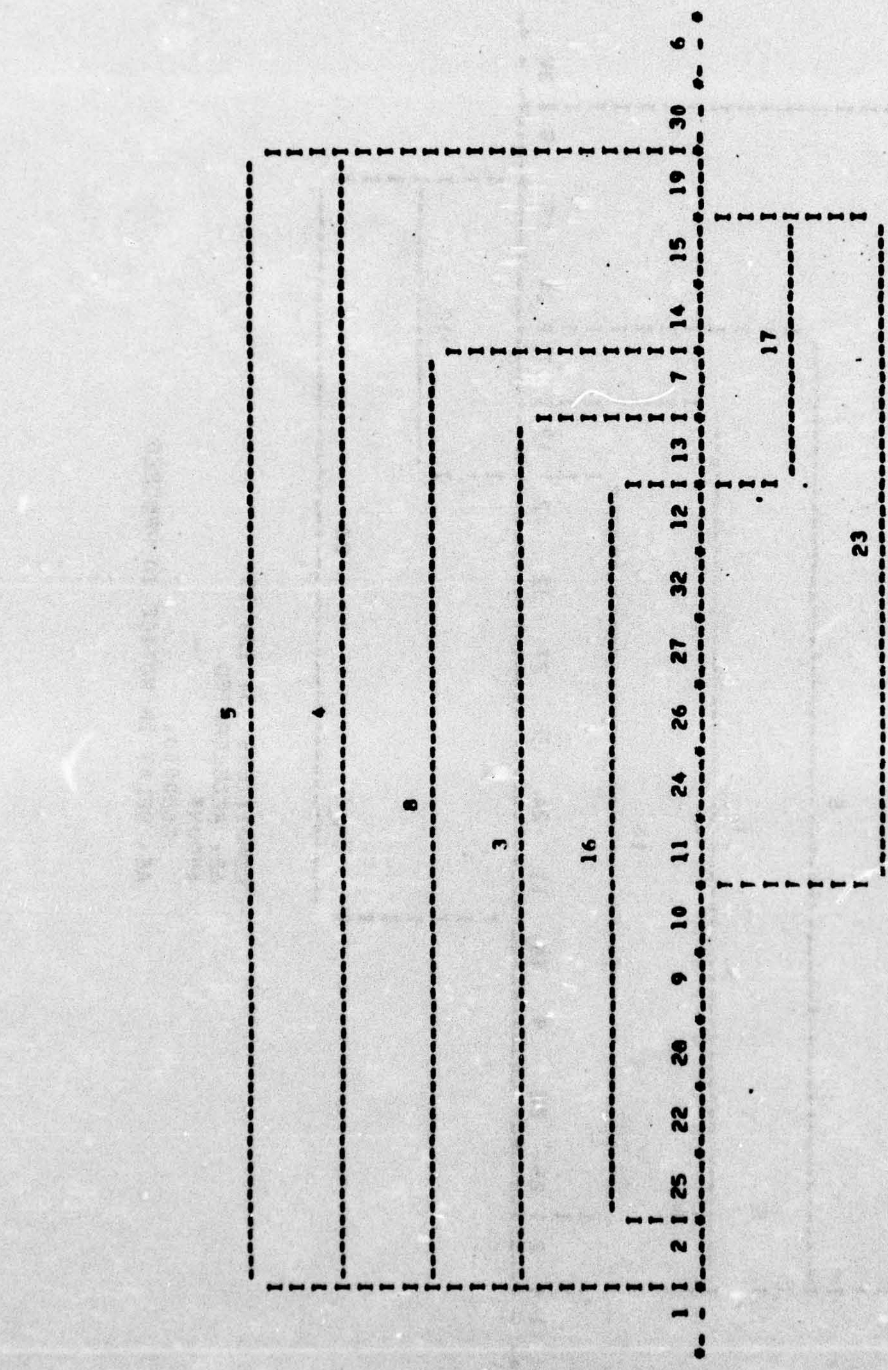
CONDITIONS: 3, 12, 14
AE, ACCELERATED
AMOUNT
600000.



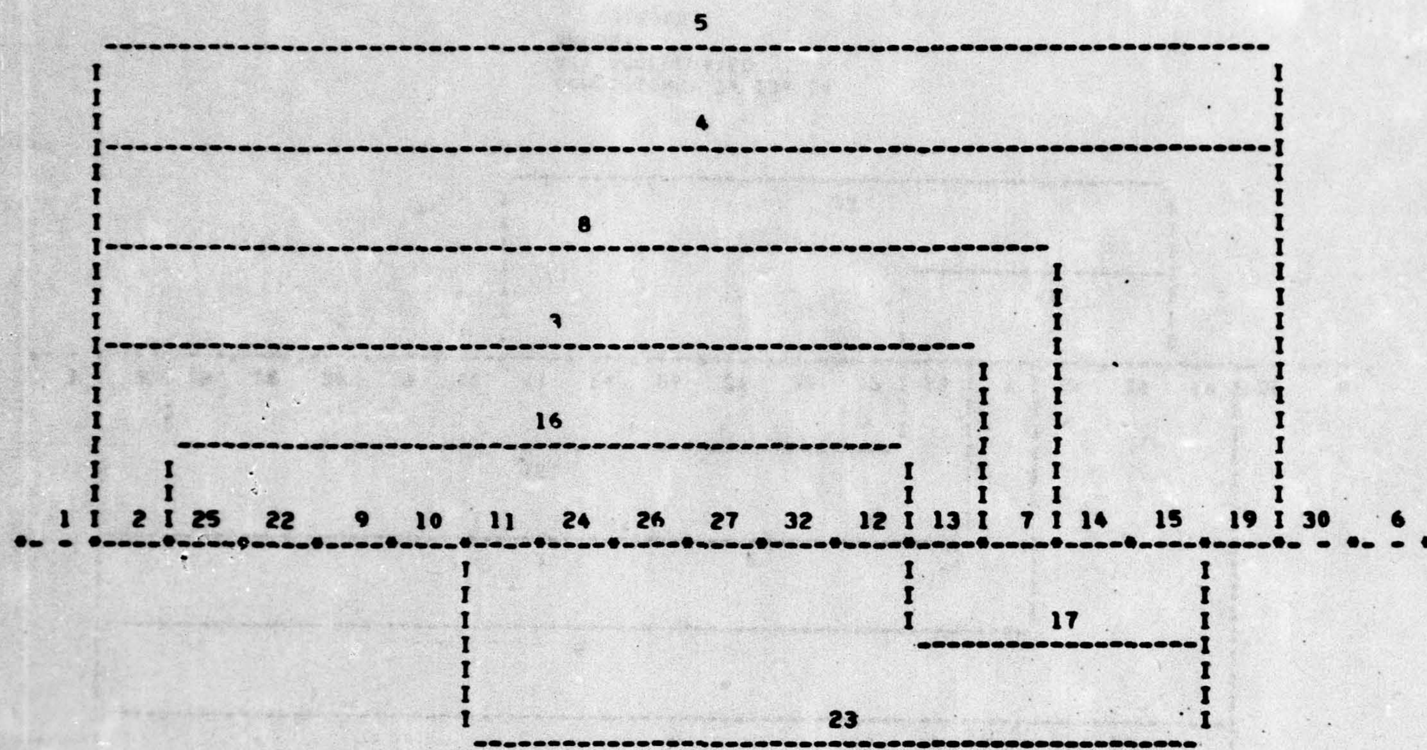
CONDITIONS: 3, 12, 15
AE, ACCELERATED
AMOUNT
    600000.
AE, DELAY IN NOTICE TO PROCEED



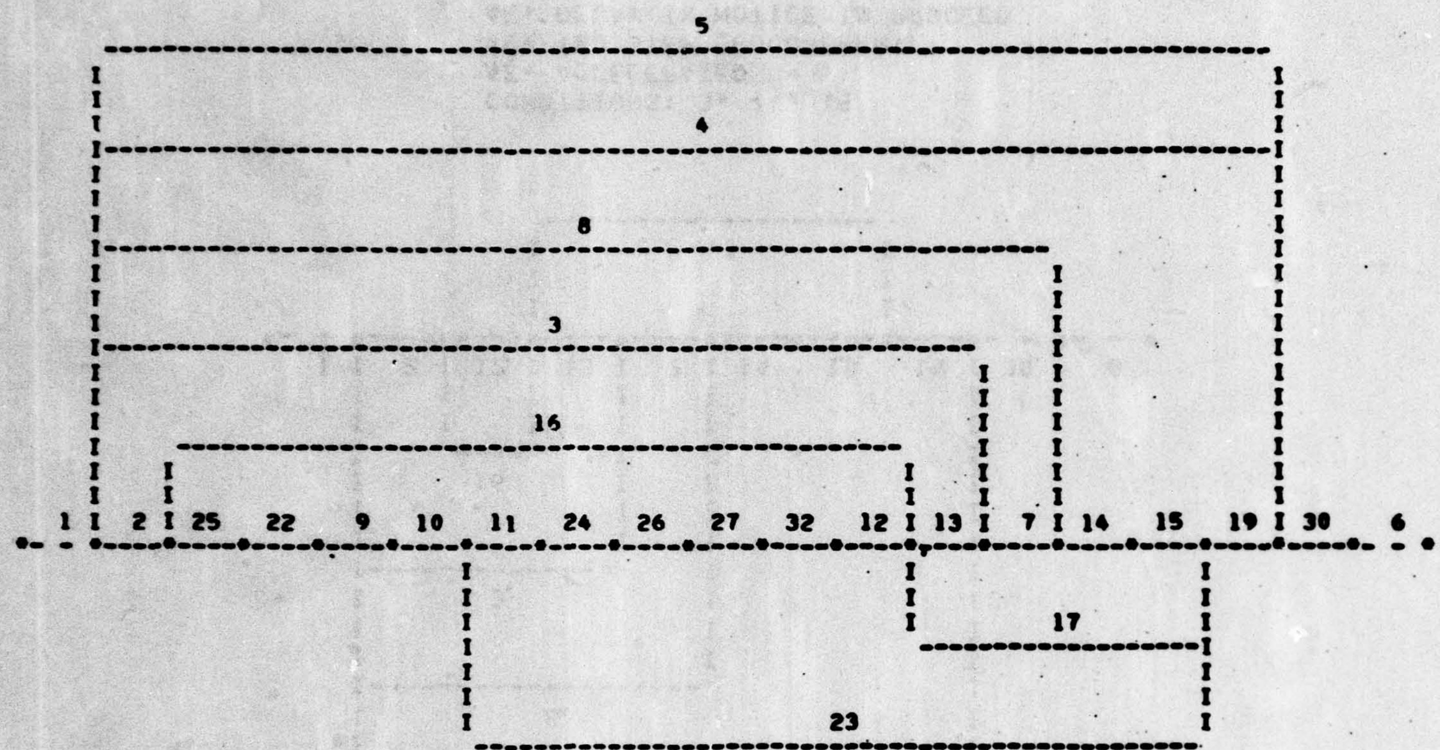
CONDITIONS: 3, 12, 16
AE, ACCELERATED
AMOUNT
    600000.
AE, DELAY IN DES DIRECTIVE



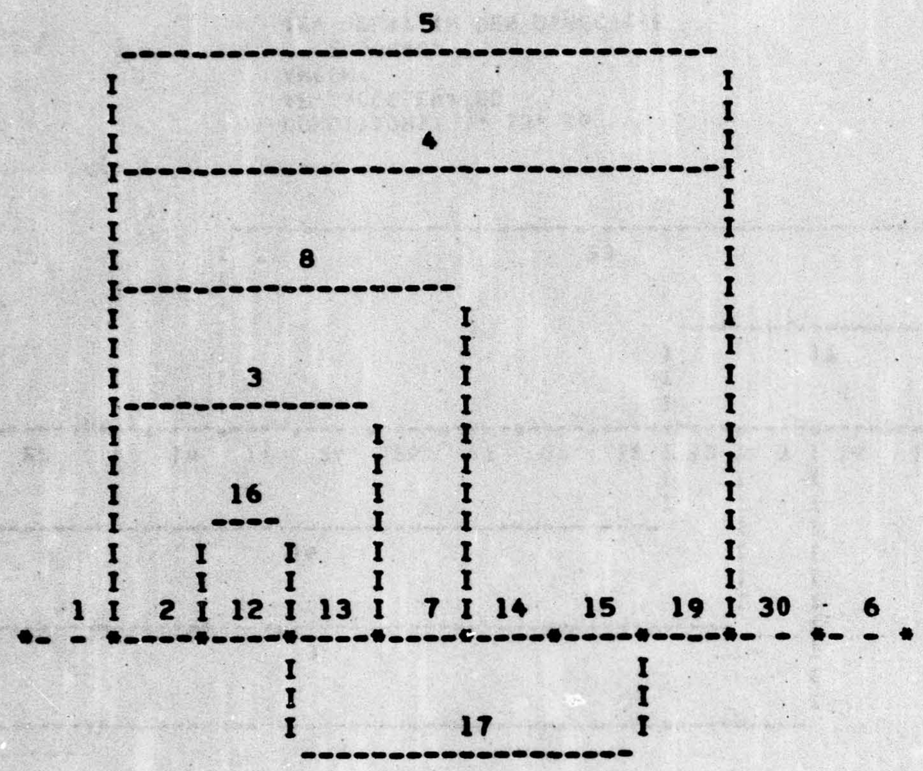
CONDITIONS: 3, 13, 14
AE, ACCELERATED
AMOUNT
2000000.



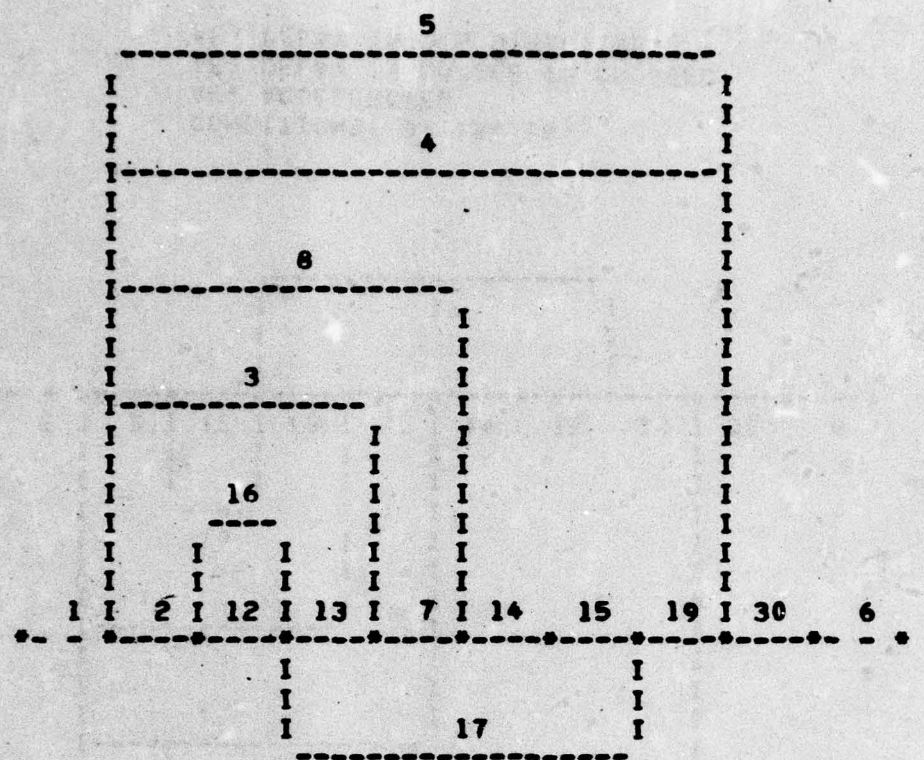
CONDITIONS: 3, 13, 15
AE, ACCELERATED
AMOUNT
2000000.
AE, DELAY IN NOTICE TO PROCEED



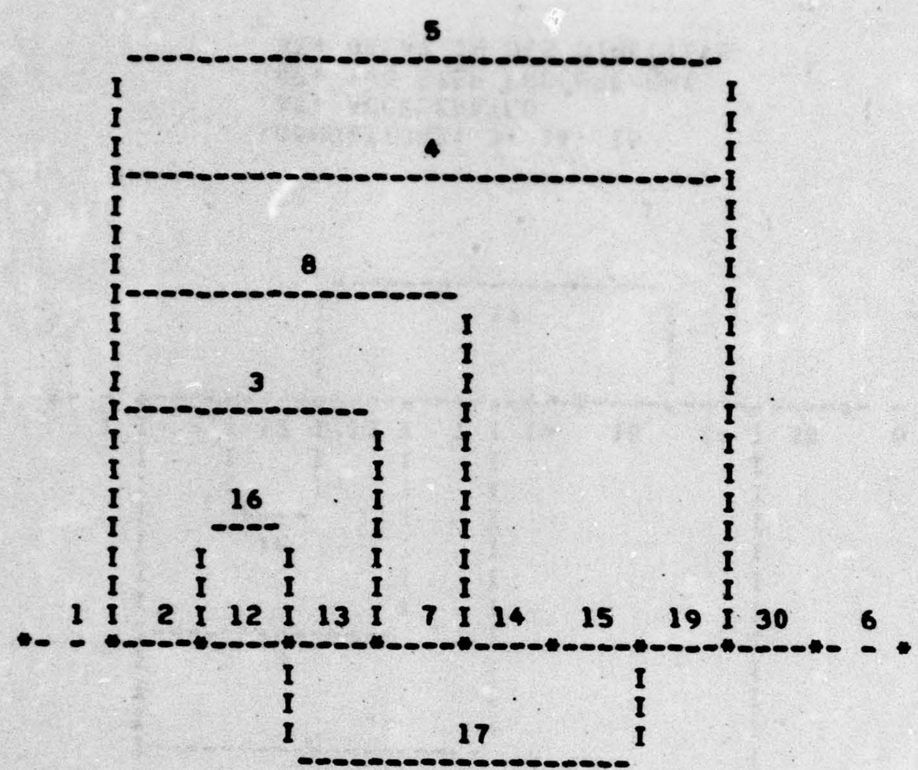
CONDITIONS: 3, 13, 16
AE, ACCELERATED
AMOUNT
2000000.
AE, DELAY IN DES DIRECTIVE



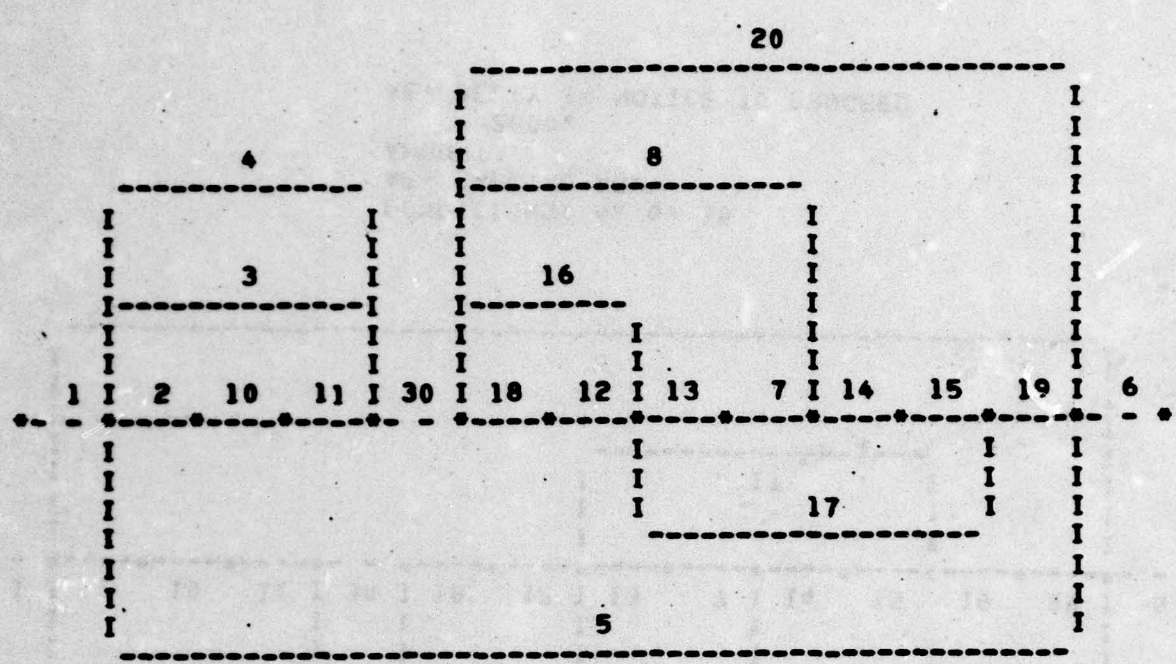
CONDITIONS: 3, 14, 15
AE, ACCELERATED
AE, TWO STEP PROCUREMENT
AE, DELAY IN NOTICE TO PROCEED



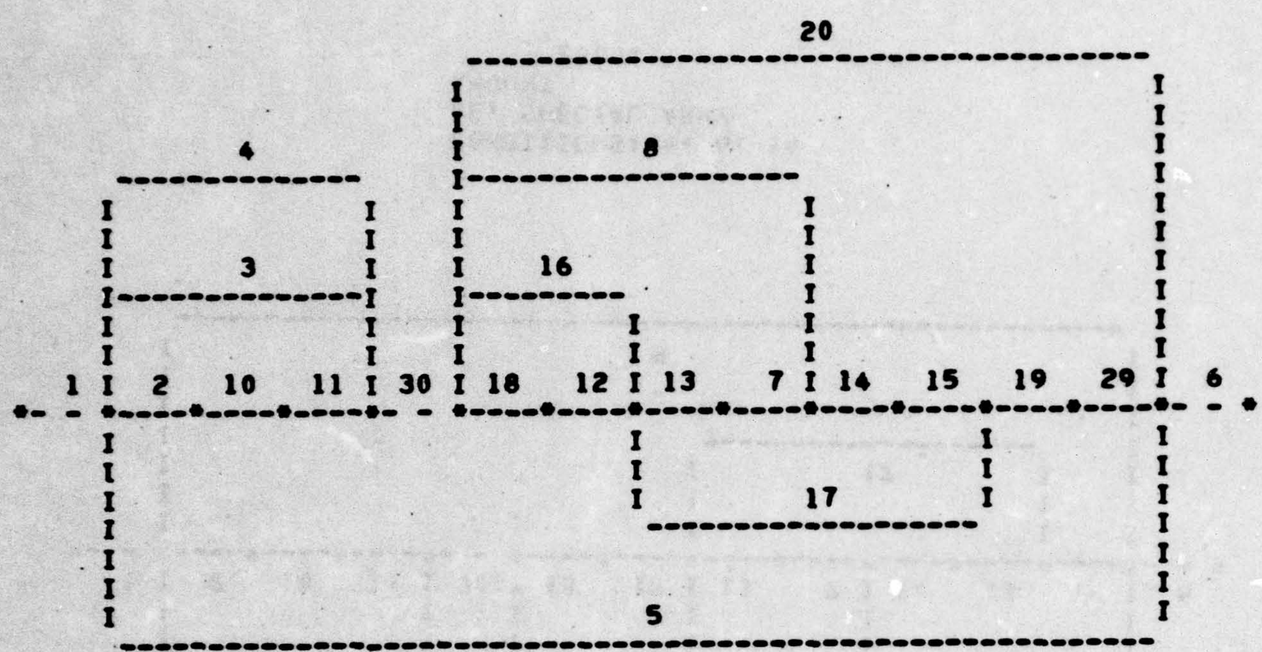
CONDITIONS: 3, 14, 16
AE, ACCELERATED
AE, TWO STEP PROCUREMENT
AE, DELAY IN DES DIRECTIVE



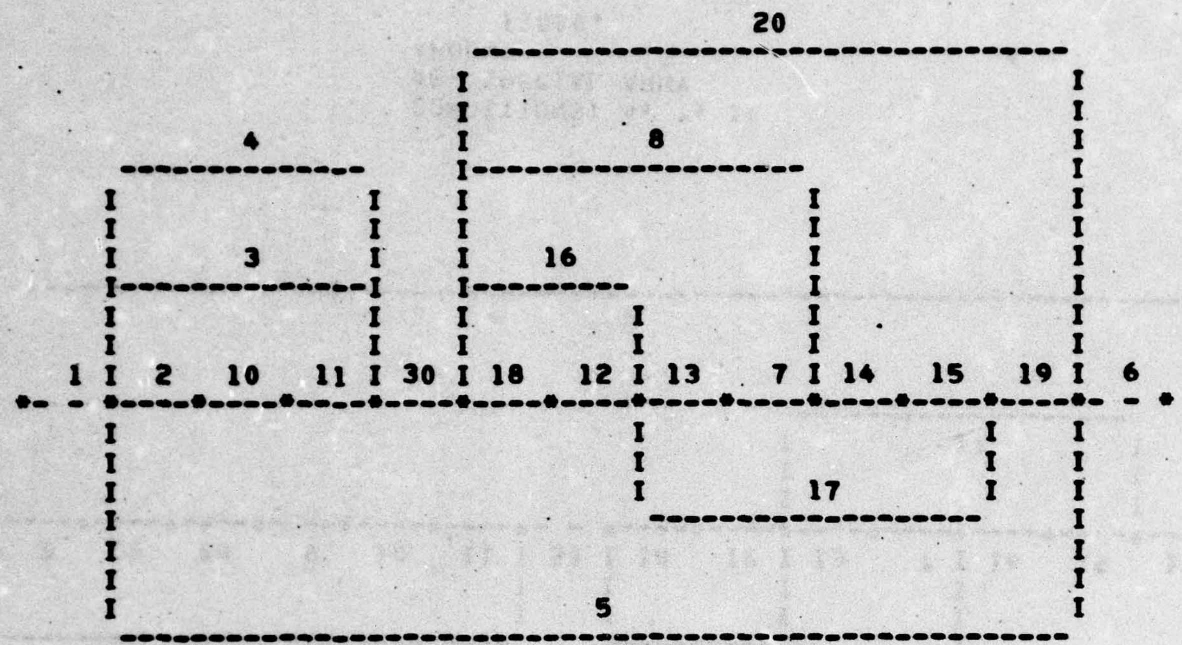
CONDITIONS: 3, 15, 16
AE, ACCELERATED
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



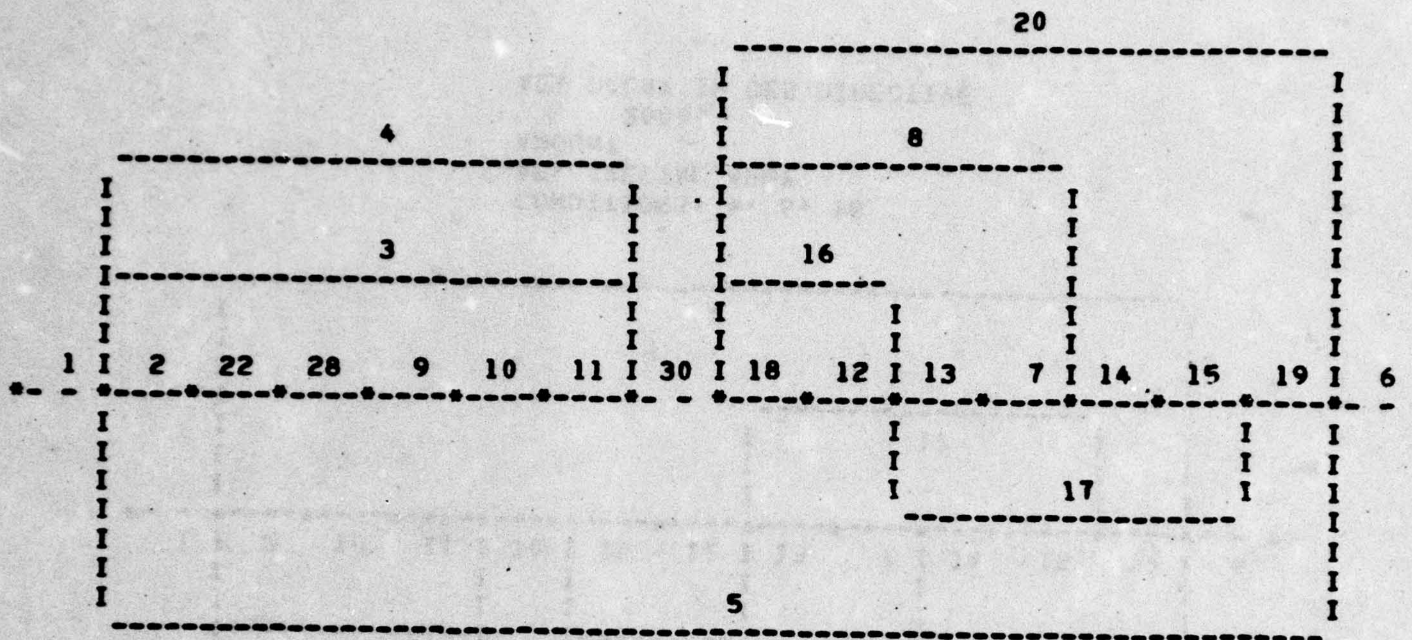
CONDITIONS: 4, 6, 14
AE, SPECIAL ARMY
AMOUNT
2600.



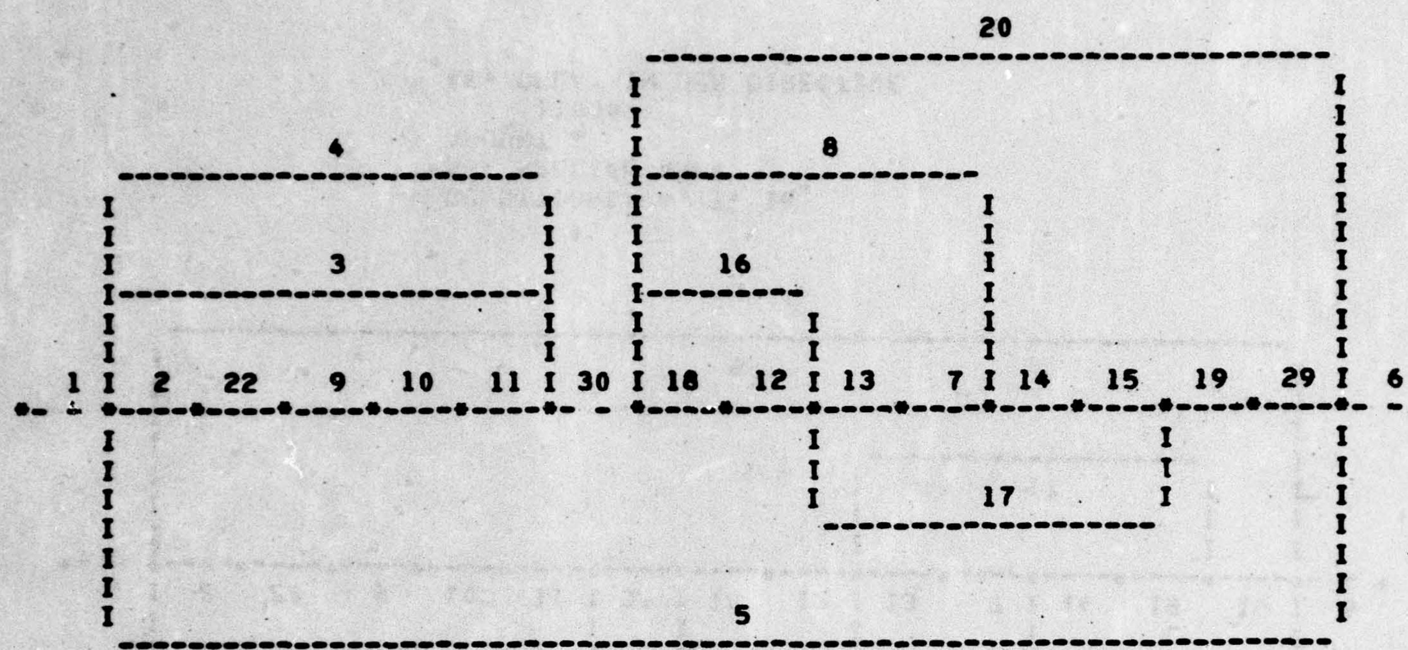
CONDITIONS: 4, 6, 15
AE, SPECIAL ARMY
AMOUNT
2600.
AE, DELAY IN NOTICE TO PROCEED



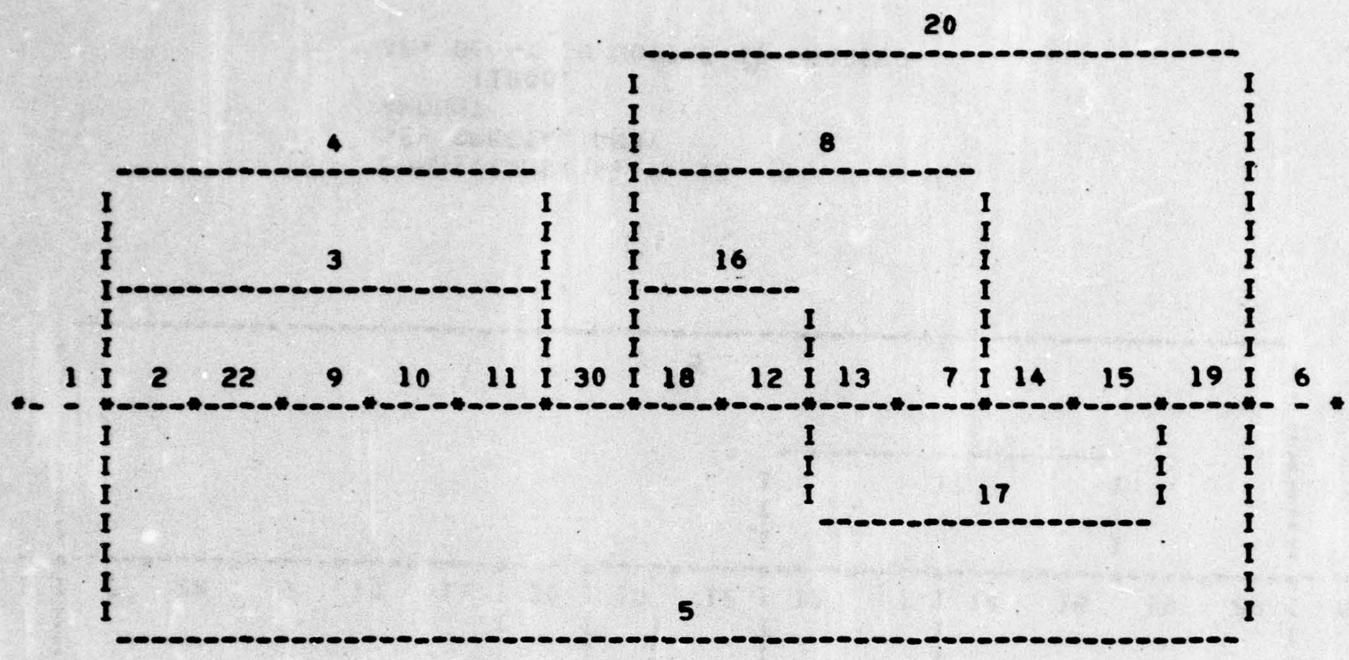
CONDITIONS: 4, 6, 16
AE, SPECIAL ARMY
AMOUNT
2600.
AE, DELAY IN DES DIRECTIVE



CONDITIONS: 4, 7, 14
AE, SPECIAL ARMY
AMOUNT
11000.



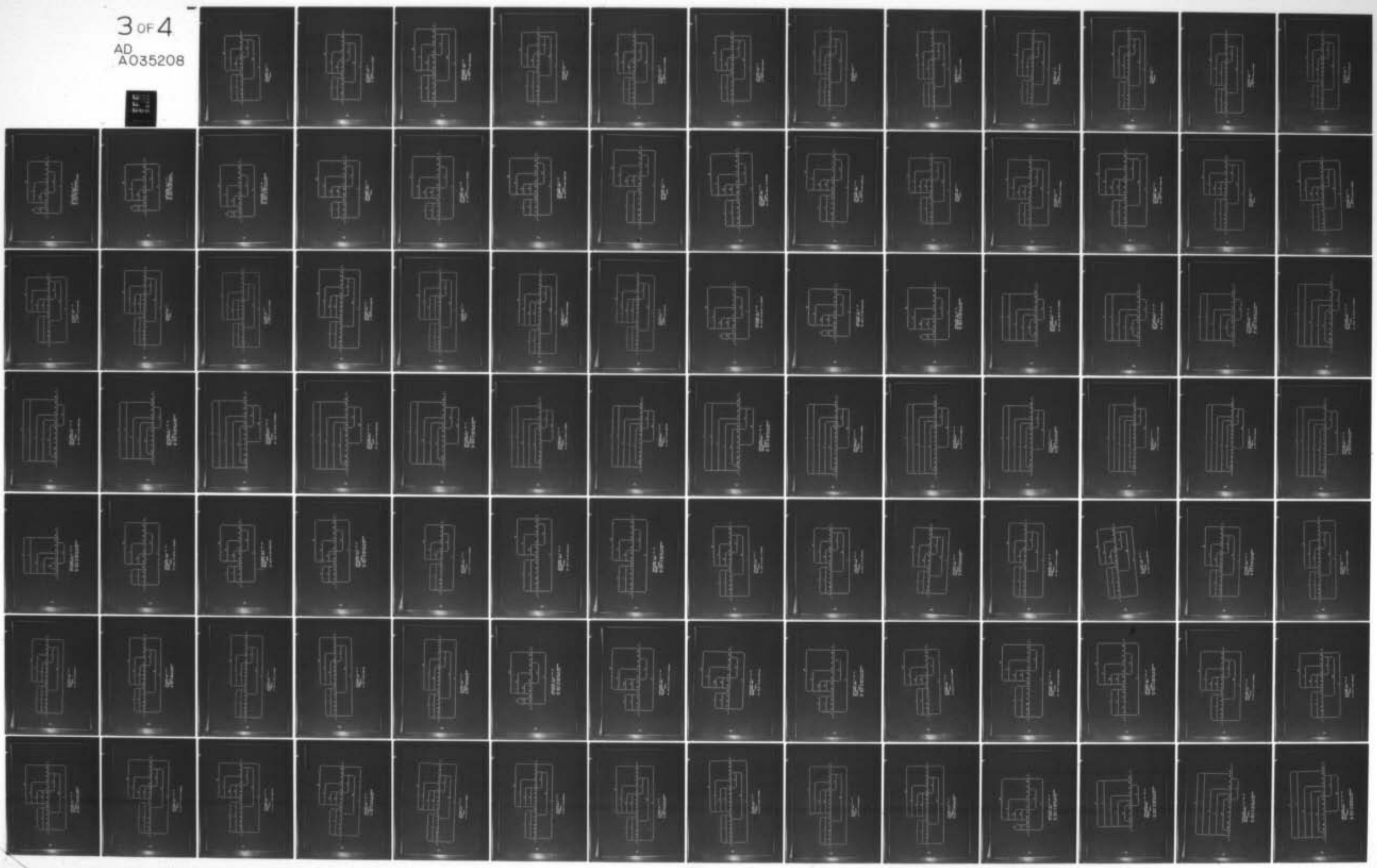
CONDITIONS: 4, 7, 15
AE, SPECIAL ARMY
AMOUNT
11000.
AE, DELAY IN NOTICE TO PROCEED

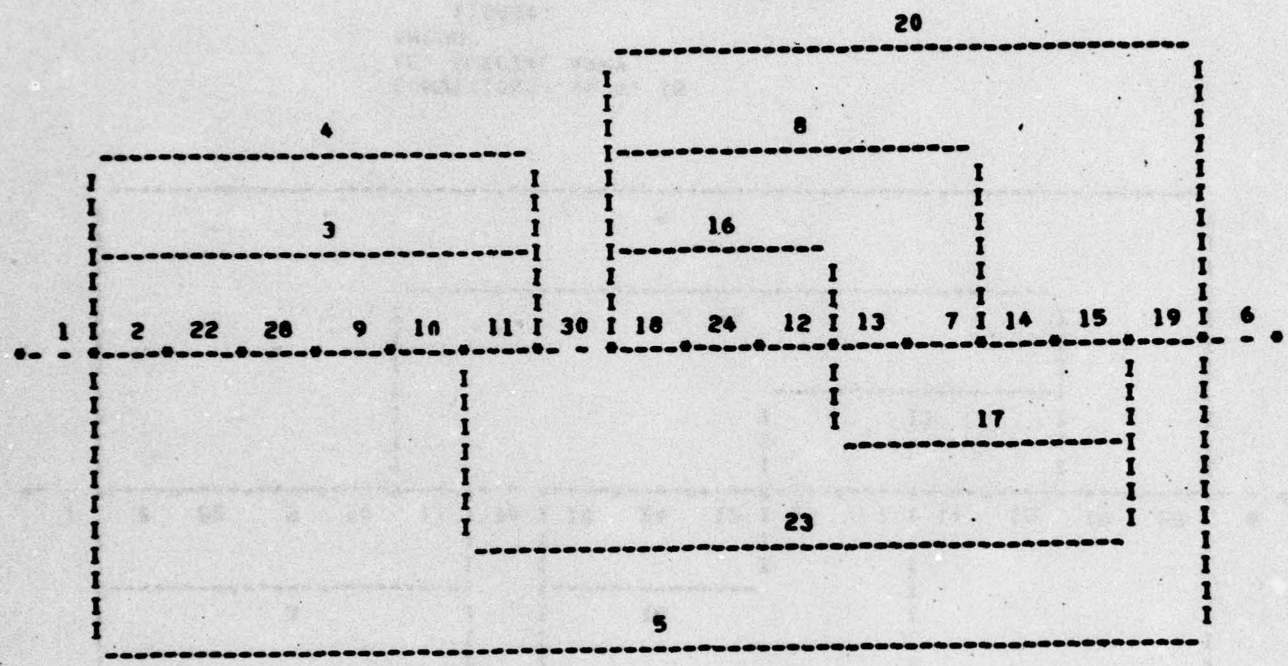


CONDITIONS: 4, 7, 16
AE, SPECIAL ARMY
AMOUNT
11000.
AE, DELAY IN DES DIRECTIVE

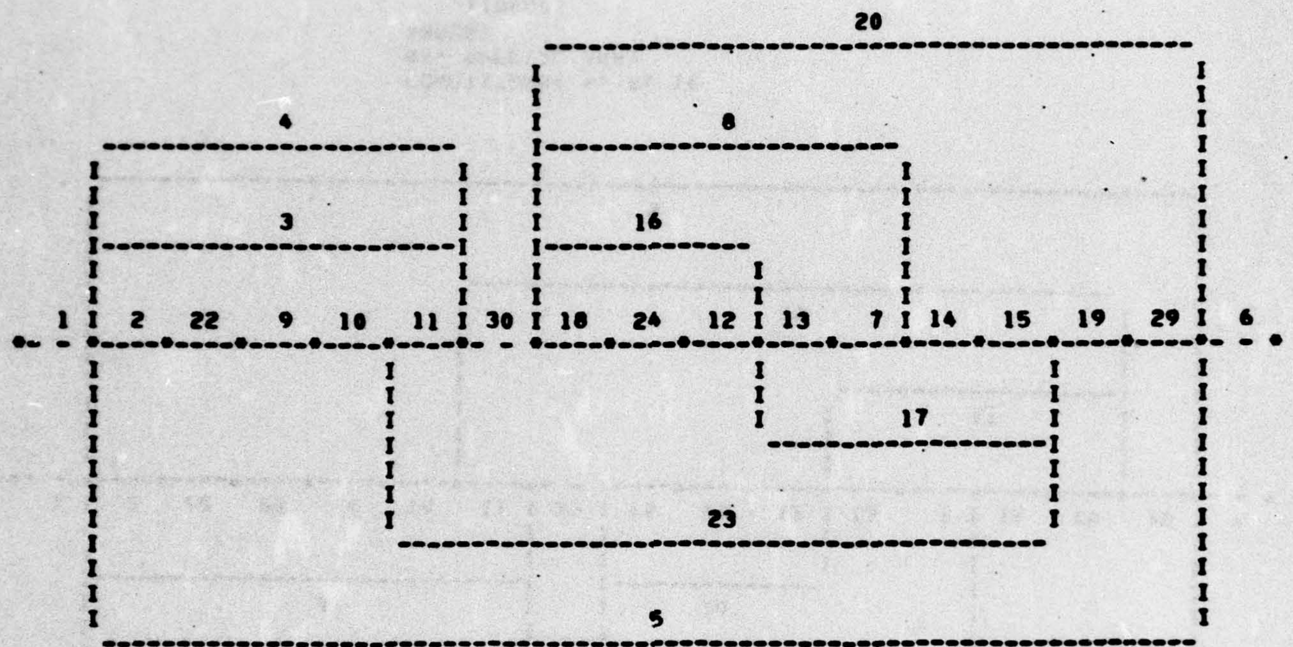
AD-A035 208 CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAI--ETC F/G 5/1
ENGINEERING AND DESIGN PERFORMANCE ANALYSIS.(U)
DEC 76 R L LAPP, J G KIRBY
UNCLASSIFIED CERL-IR-C-75 NL

3 OF 4
AD
A035208

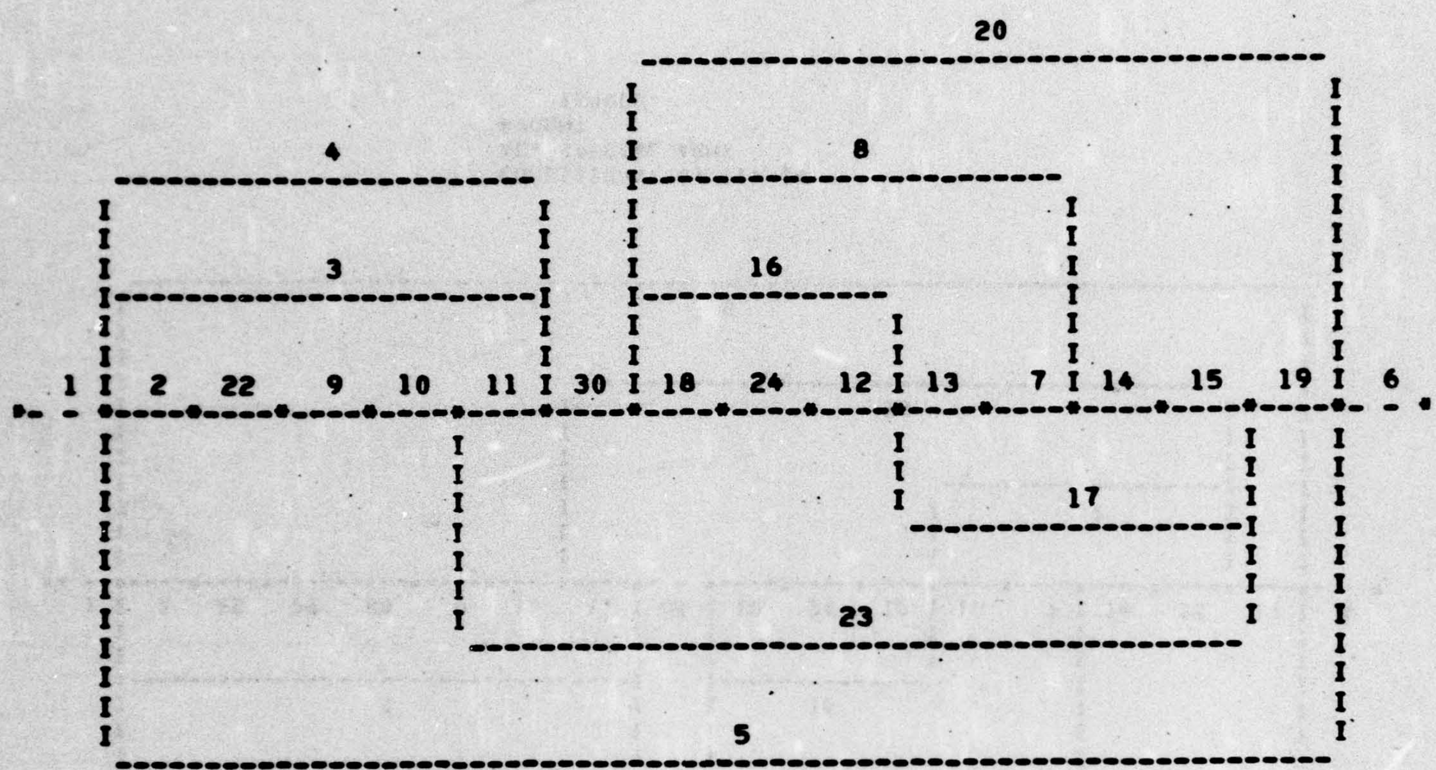




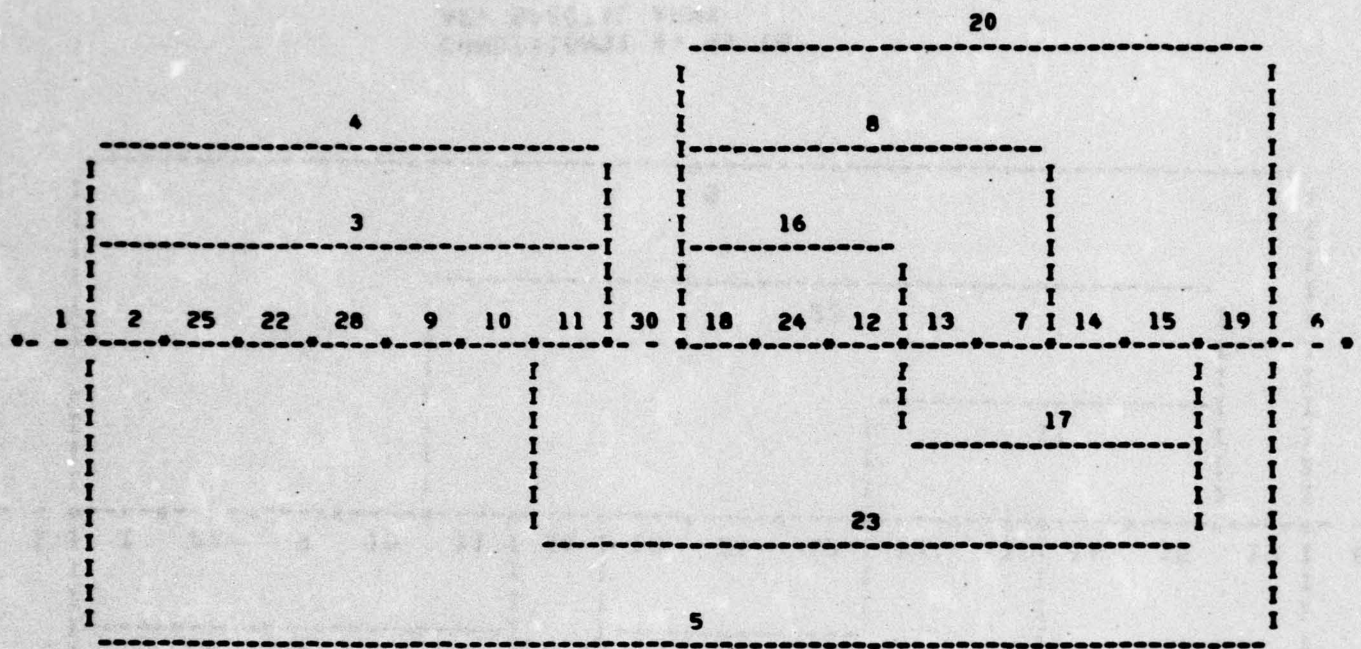
CONDITIONS: 4, 9, 14
AE, SPECIAL ARMY
AMOUNT
110000.



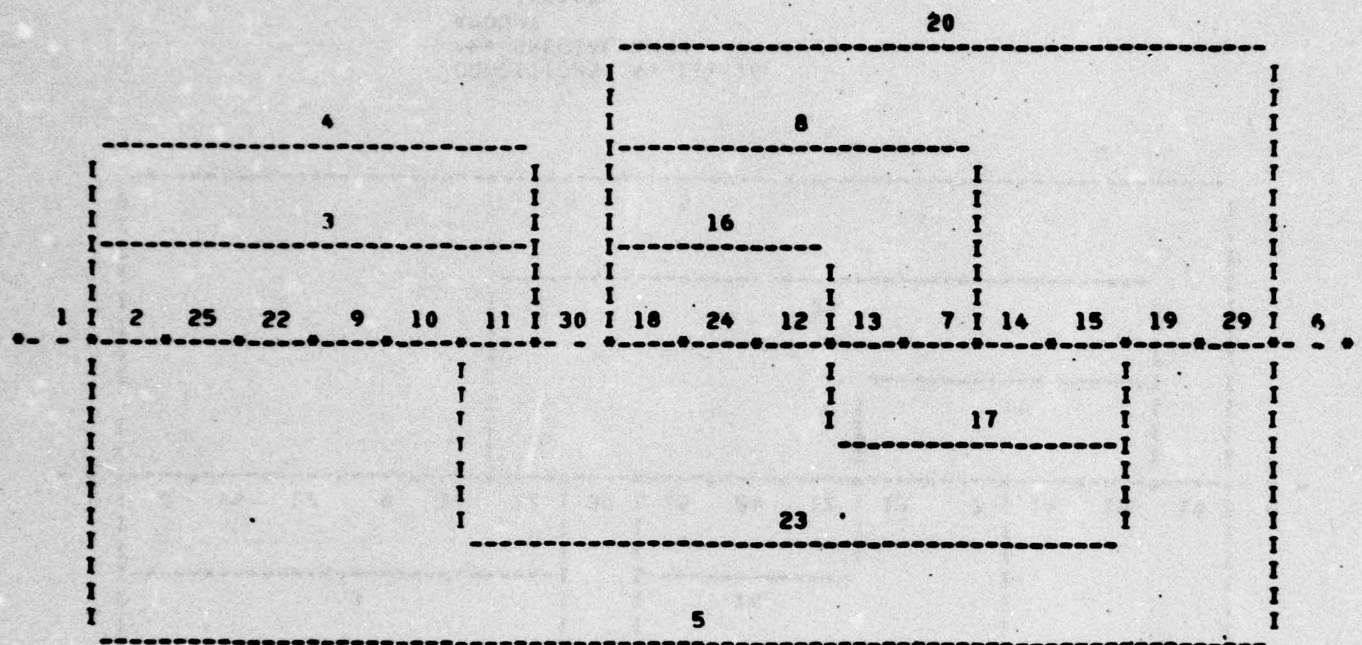
CONDITIONS: 4, 9, 15
AE, SPECIAL ARMY
AMOUNT
    110000.
AE, DELAY IN NOTICE TO PROCEED



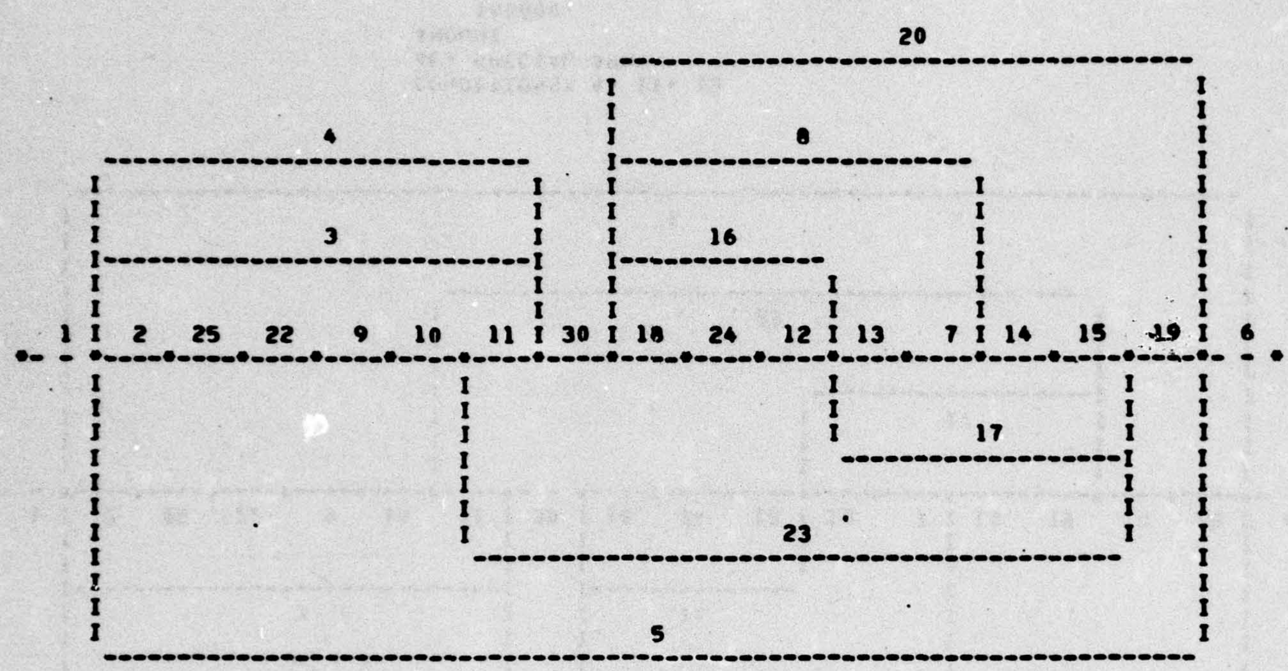
CONDITIONS: 4, 9, 16
AE, SPECIAL ARMY
AMOUNT
    110000.
AE, DELAY IN DES DIRECTIVE



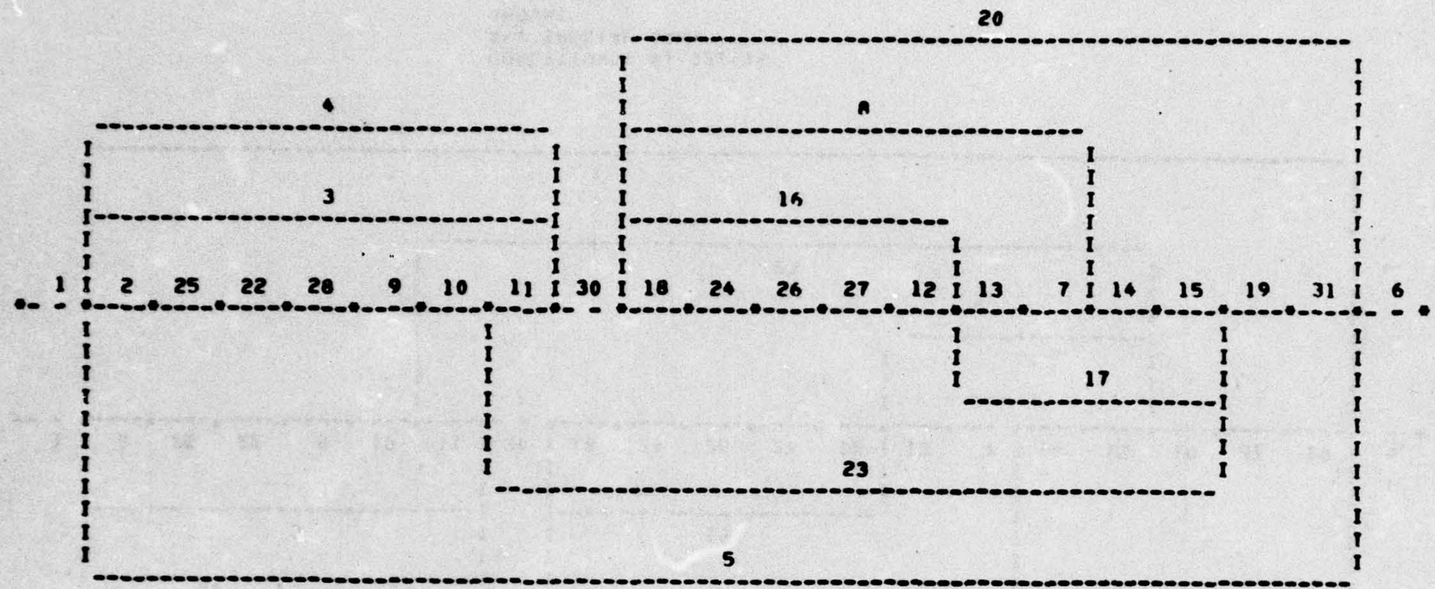
CONDITIONS: 4, 11, 14
AE, SPECIAL ARMY
AMOUNT
160000.



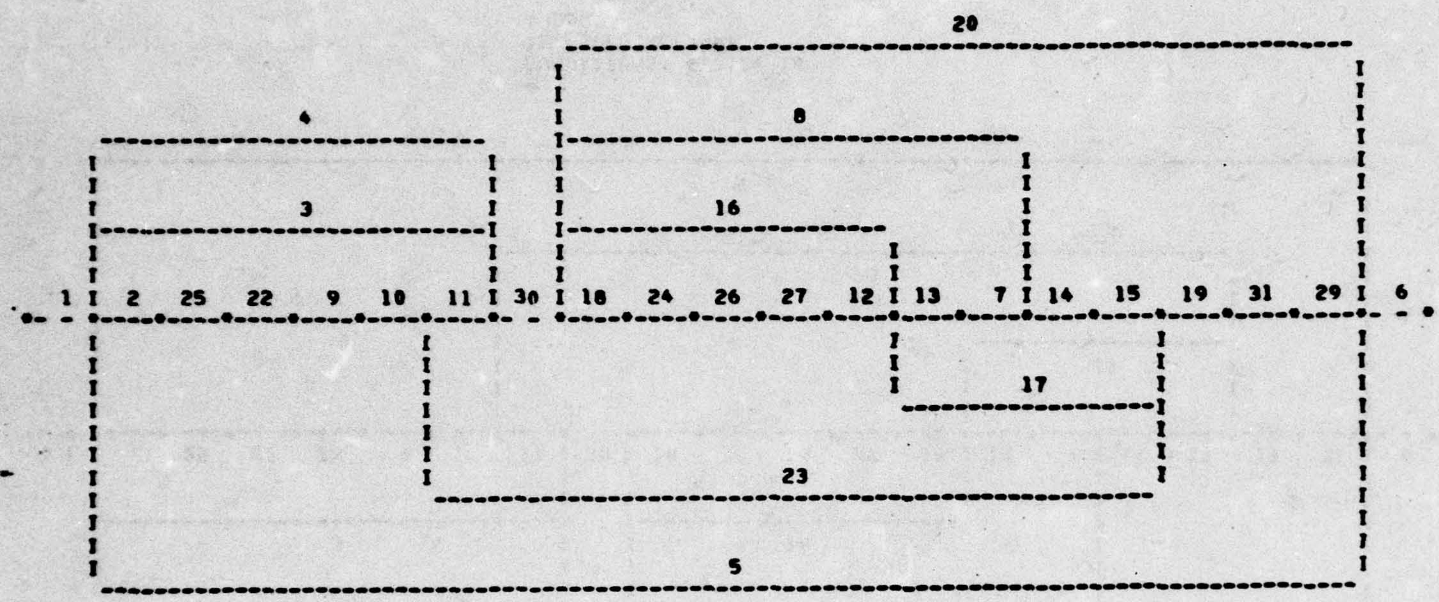
CONDITIONS: 4, 11, 15
AE, SPECIAL ARMY
AMOUNT
160000.
AE, DELAY IN NOTICE TO PROCEED



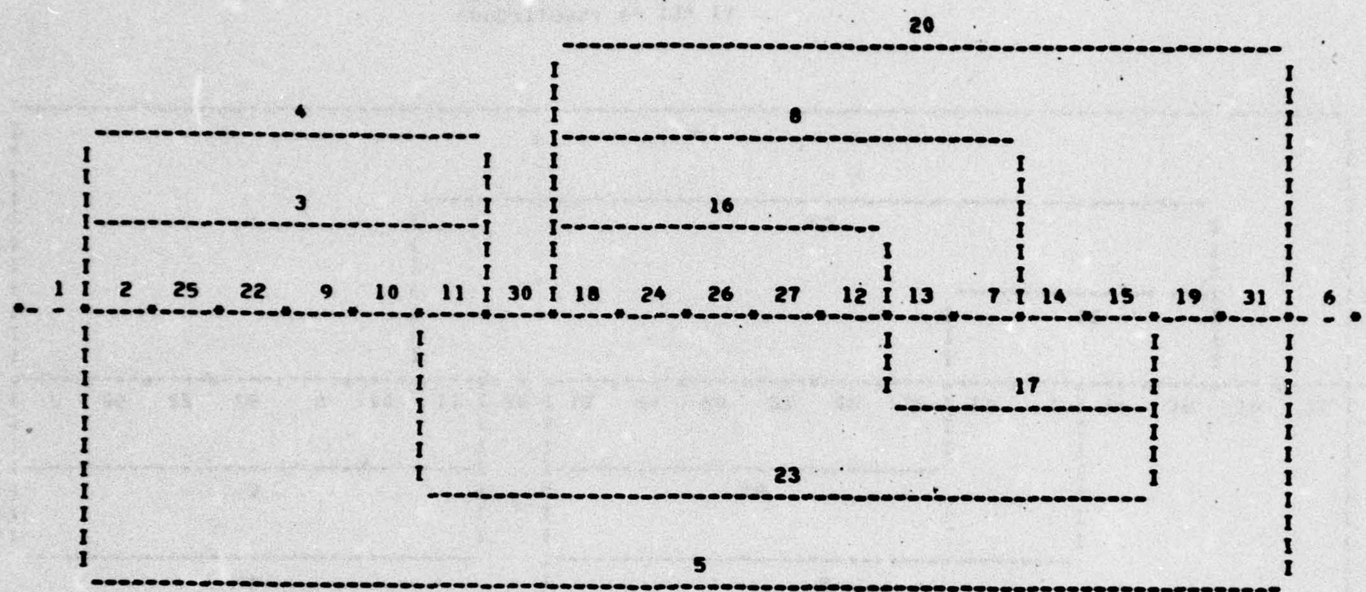
CONDITIONS: 4, 11, 16
AE, SPECIAL ARMY
AMOUNT
160000.
AE, DELAY IN DES DIRECTIVE



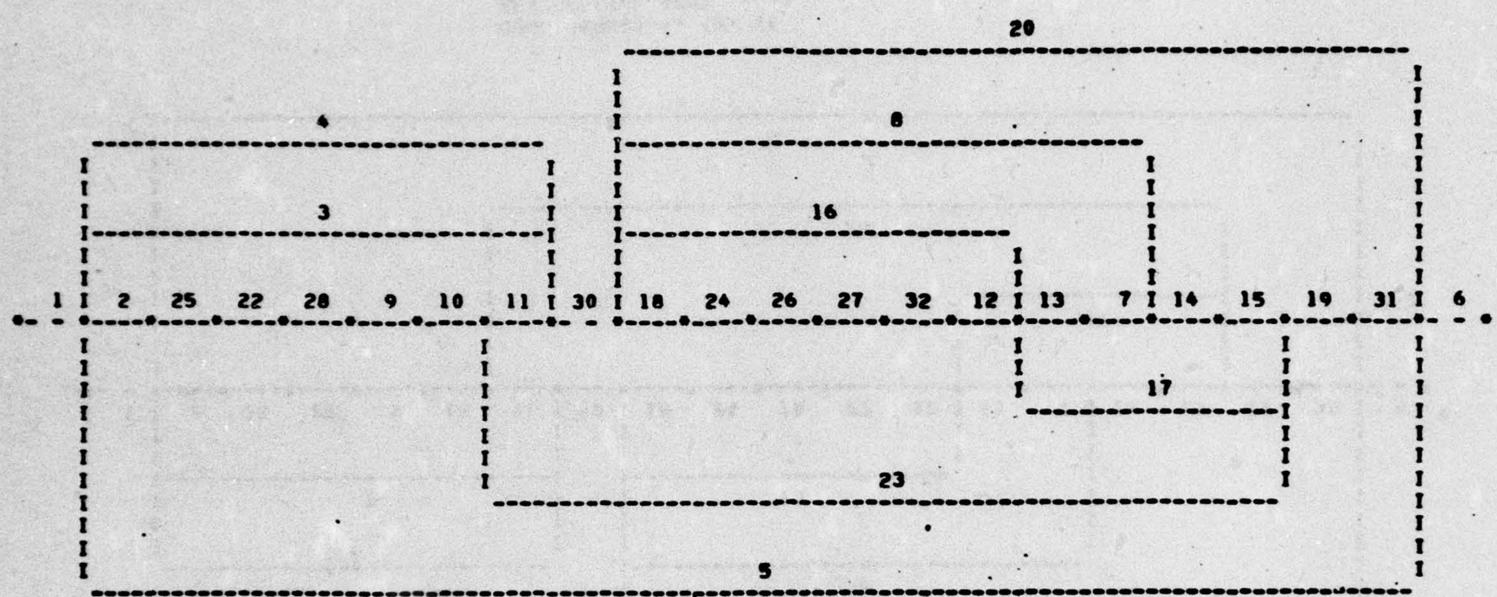
CONDITIONS: 4, 12, 14
AE, SPECIAL ARMY
AMOUNT
600000.



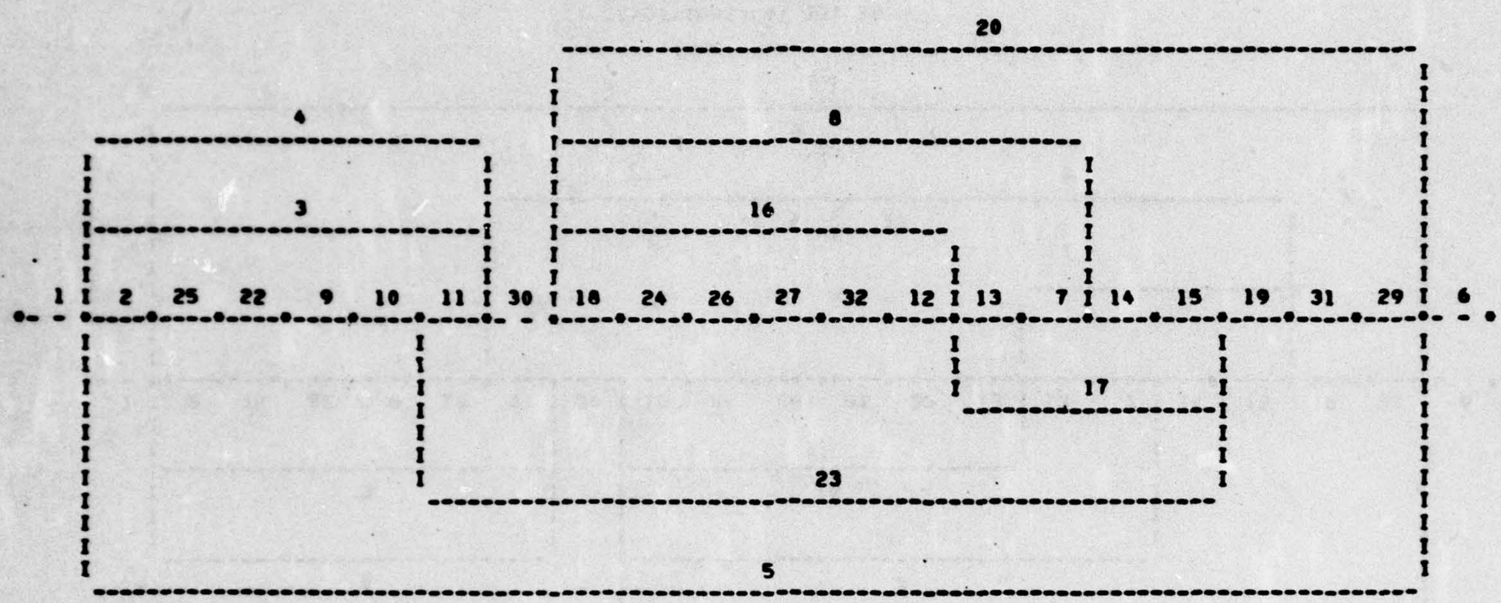
CONDITIONS: 4, 12, 15
AE, SPECIAL ARMY
AMOUNT
600000.
AE, DELAY IN NOTICE TO PROCEED



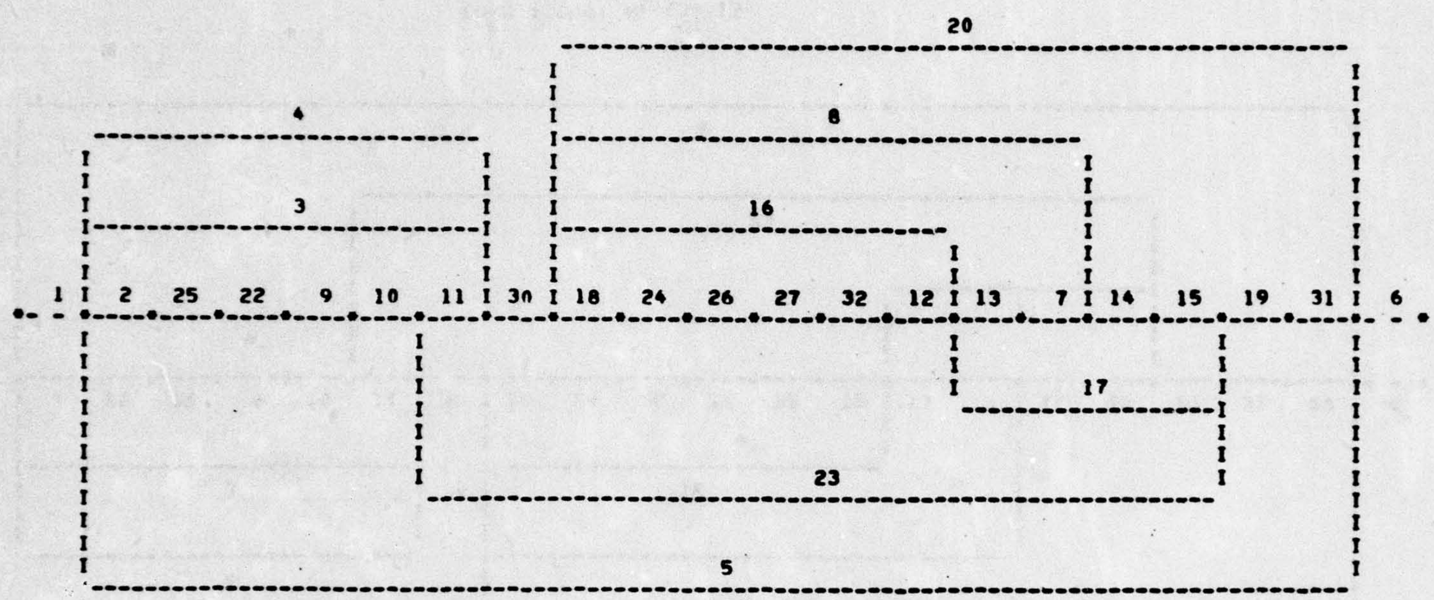
CONDITIONS: 4, 12, 16
AE, SPECIAL ARMY
AMOUNT
600000.
AE, DELAY IN DES DIRECTIVE



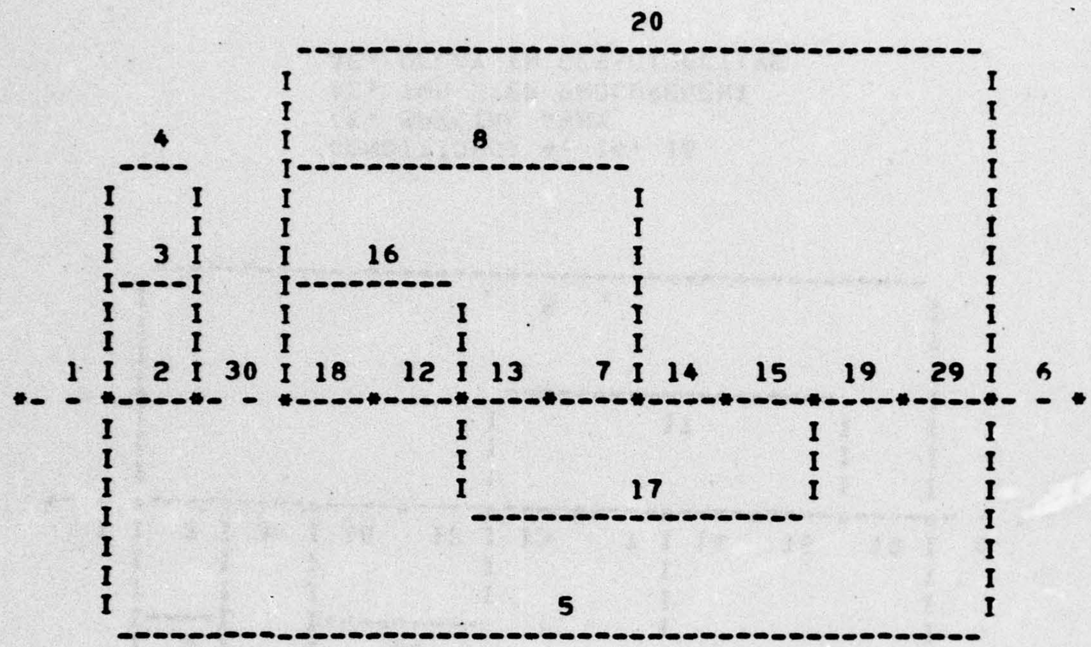
CONDITIONS: 4, 13, 14
AE, SPECIAL ARMY
AMOUNT
2000000.



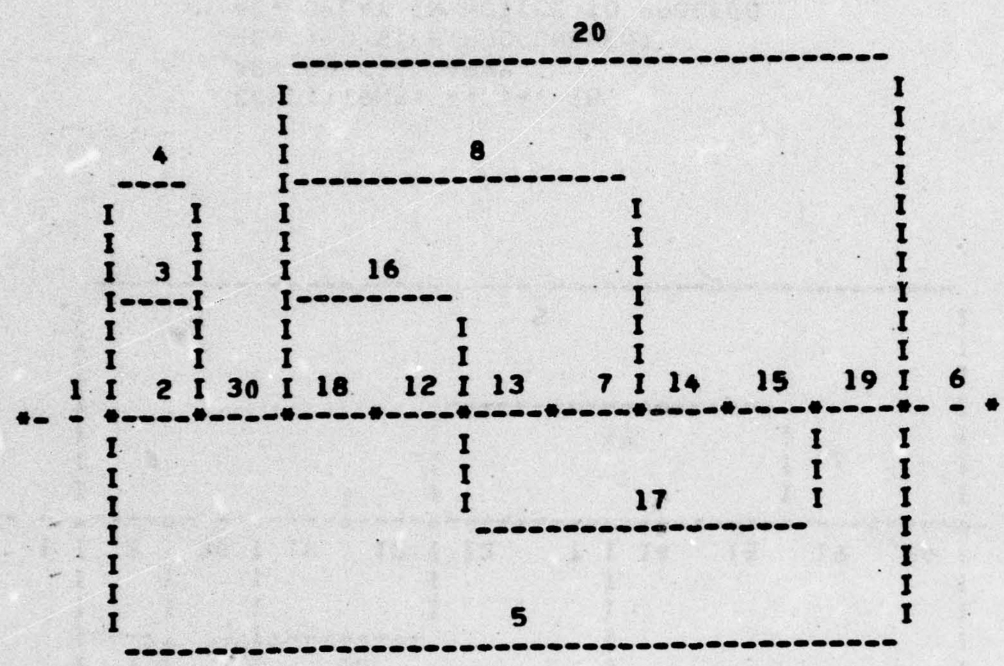
CONDITIONS: 4, 13, 15
AE, SPECIAL ARMY
AMOUNT
2000000.
AE, DELAY IN NOTICE TO PROCEED



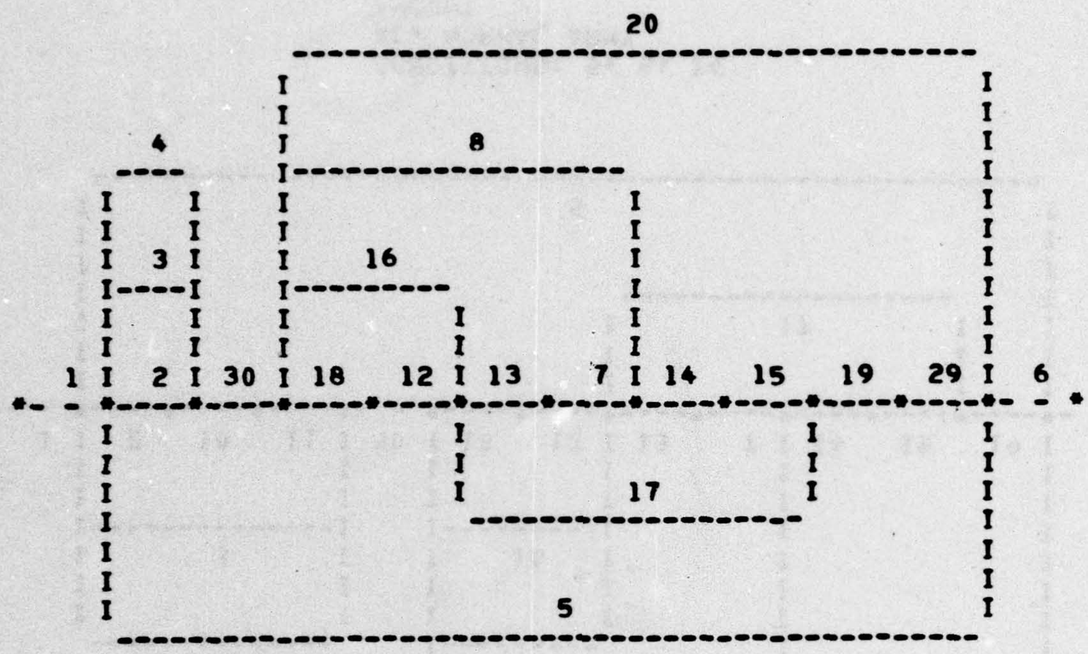
CONDITIONS: 4, 13, 16
AE, SPECIAL ARMY
AMOUNT
2000000.
AE, DELAY IN DES DIRECTIVE



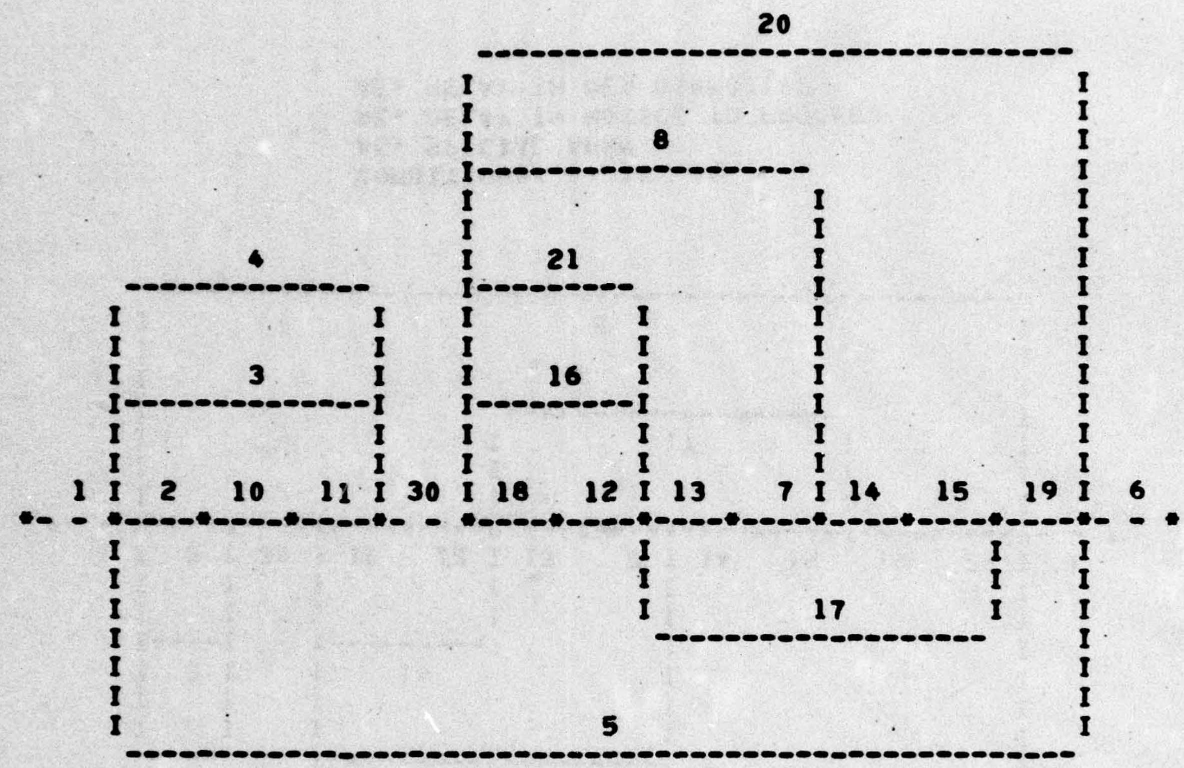
CONDITIONS: 4, 14, 15
AE, SPECIAL ARMY
AE, TWO STEP PROCUREMENT
AE, DELAY IN NOTICE TO PROCEED



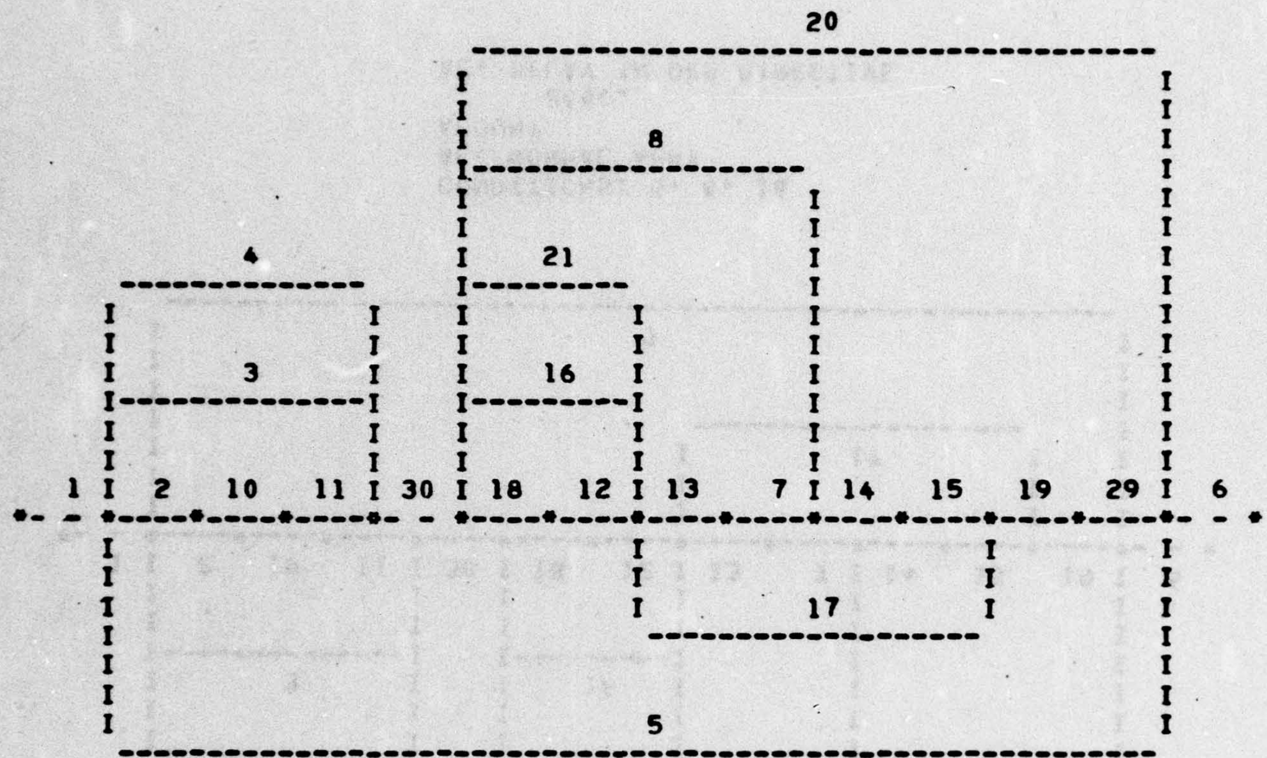
CONDITIONS: 4, 14, 16
AE, SPECIAL ARMY
AE, TWO STEP PROCUREMENT
AE, DELAY IN DES DIRECTIVE



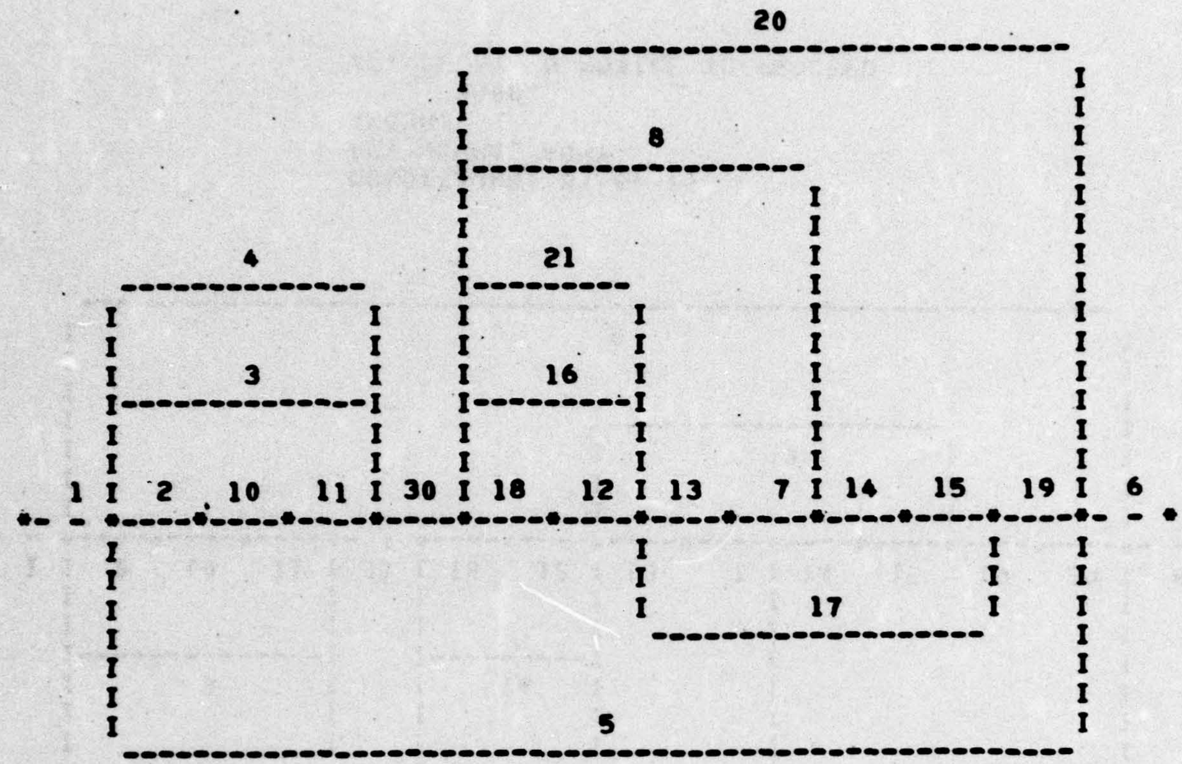
CONDITIONS: 4, 15, 16
AE, SPECIAL ARMY
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



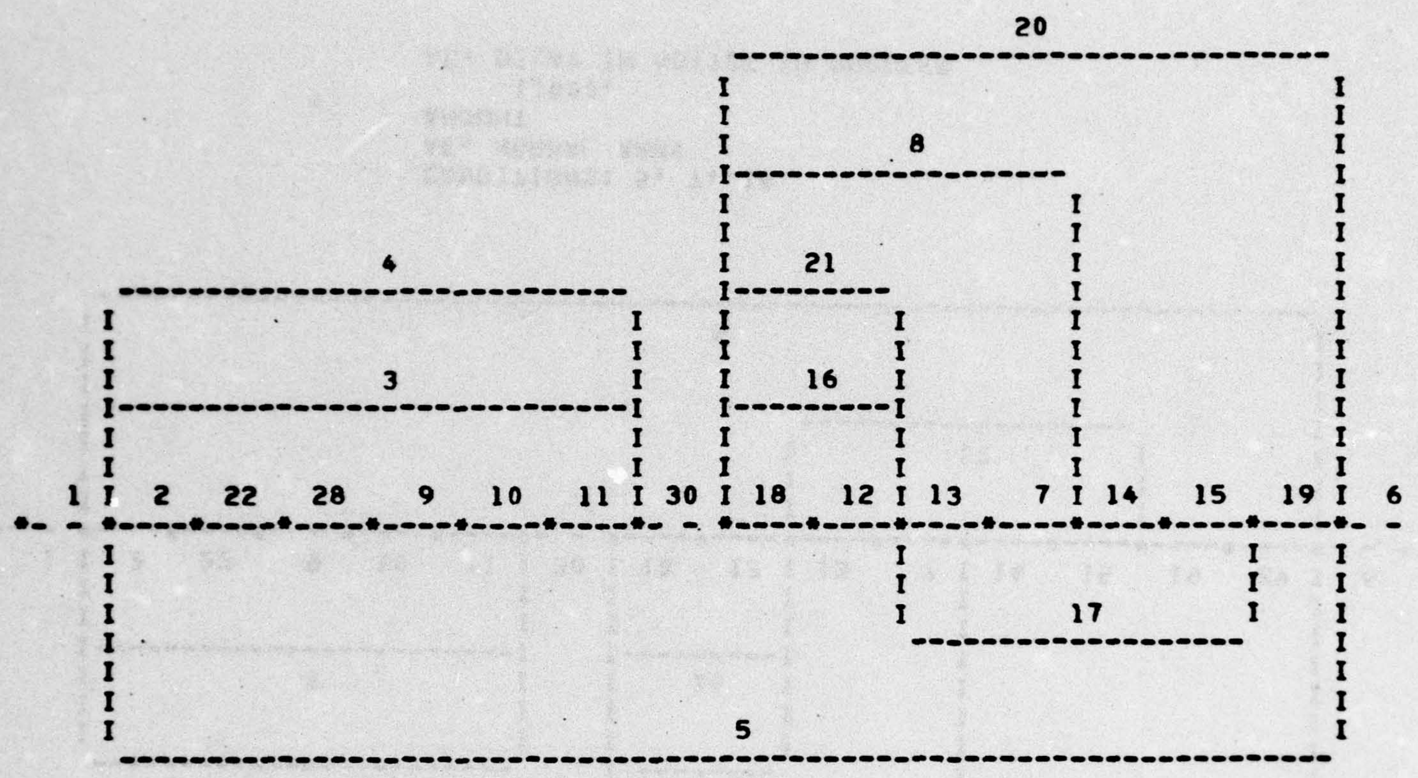
CONDITIONS: 5, 6, 14
AE, NORMAL ARMY
AMOUNT
2600.



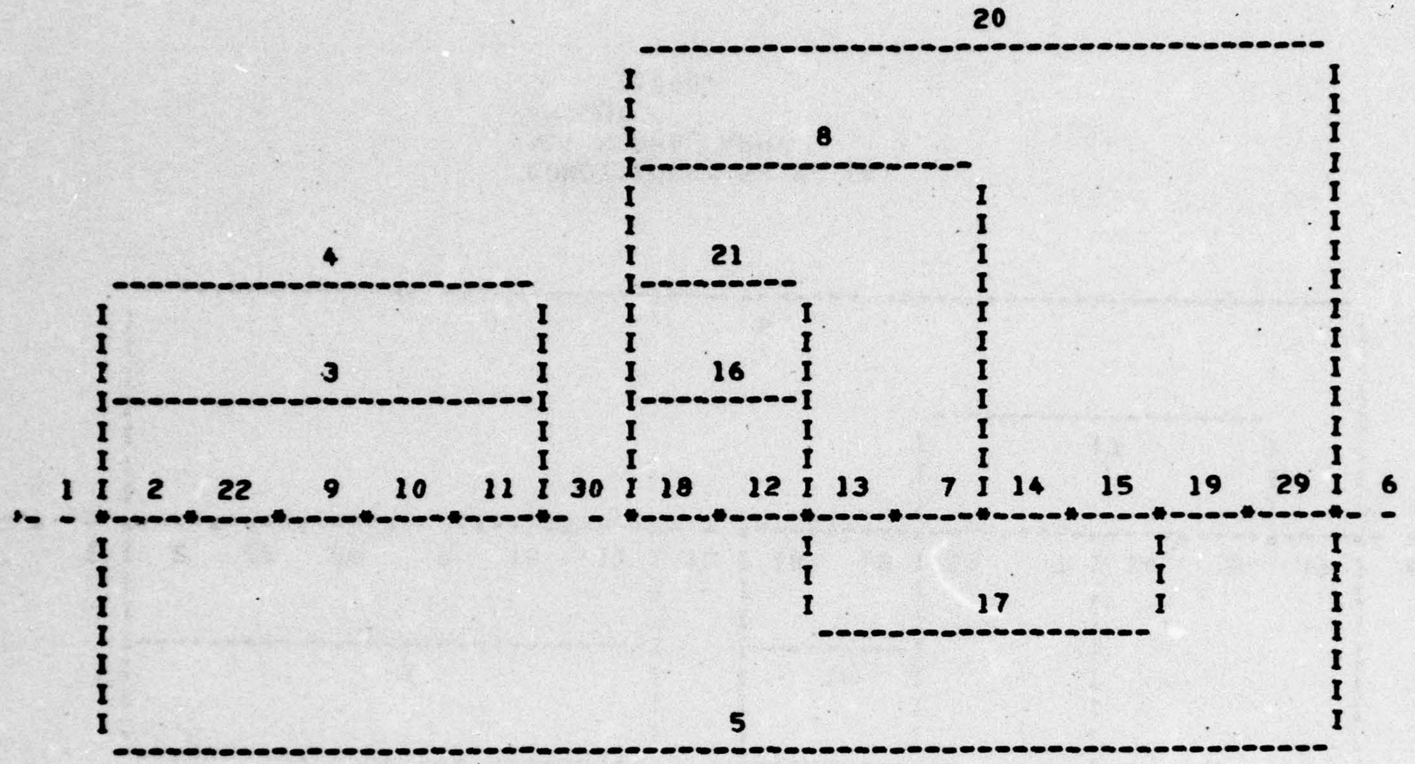
CONDITIONS: 5, 6, 15
AE, NORMAL ARMY
AMOUNT
2600.
AE, DELAY IN NOTICE TO PROCEED



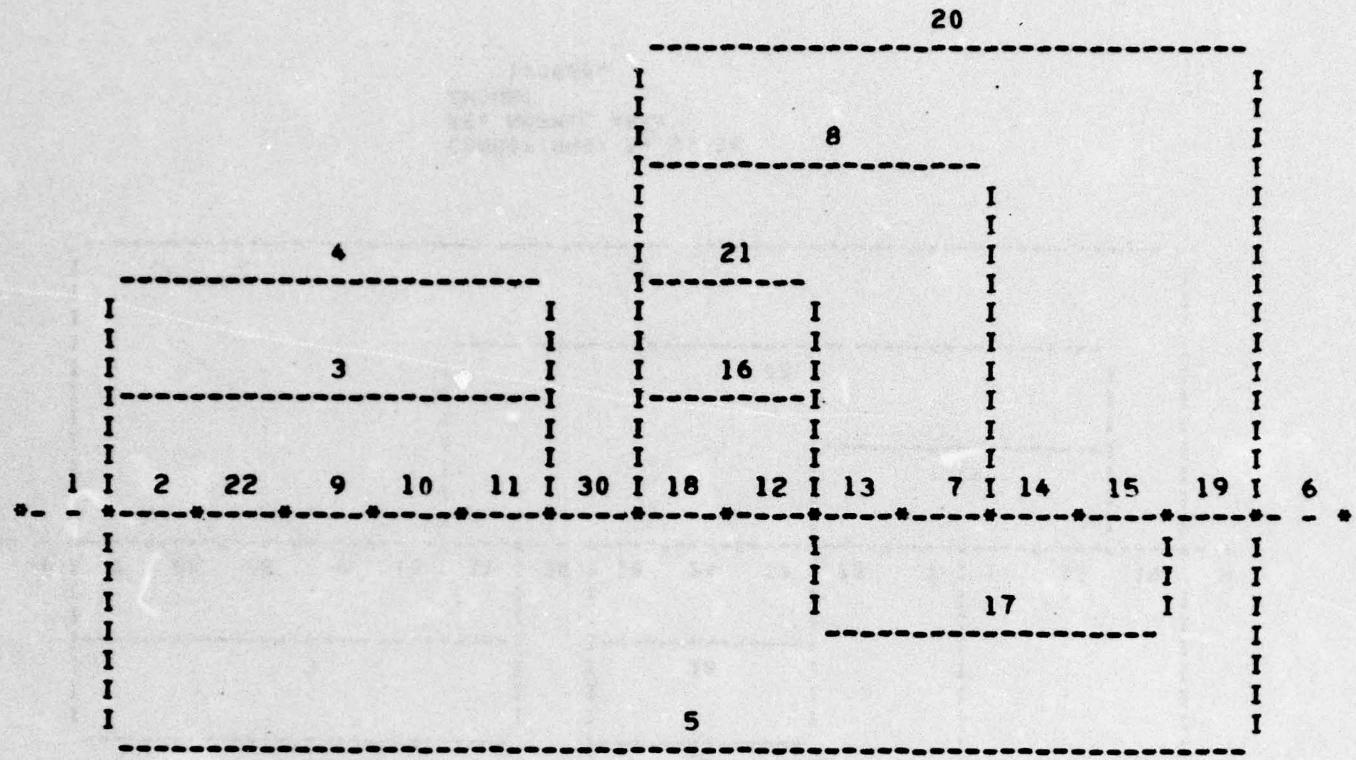
CONDITIONS: 5, 6, 16
AE, NORMAL ARMY
AMOUNT
2600.
AE, DELAY IN DES DIRECTIVE



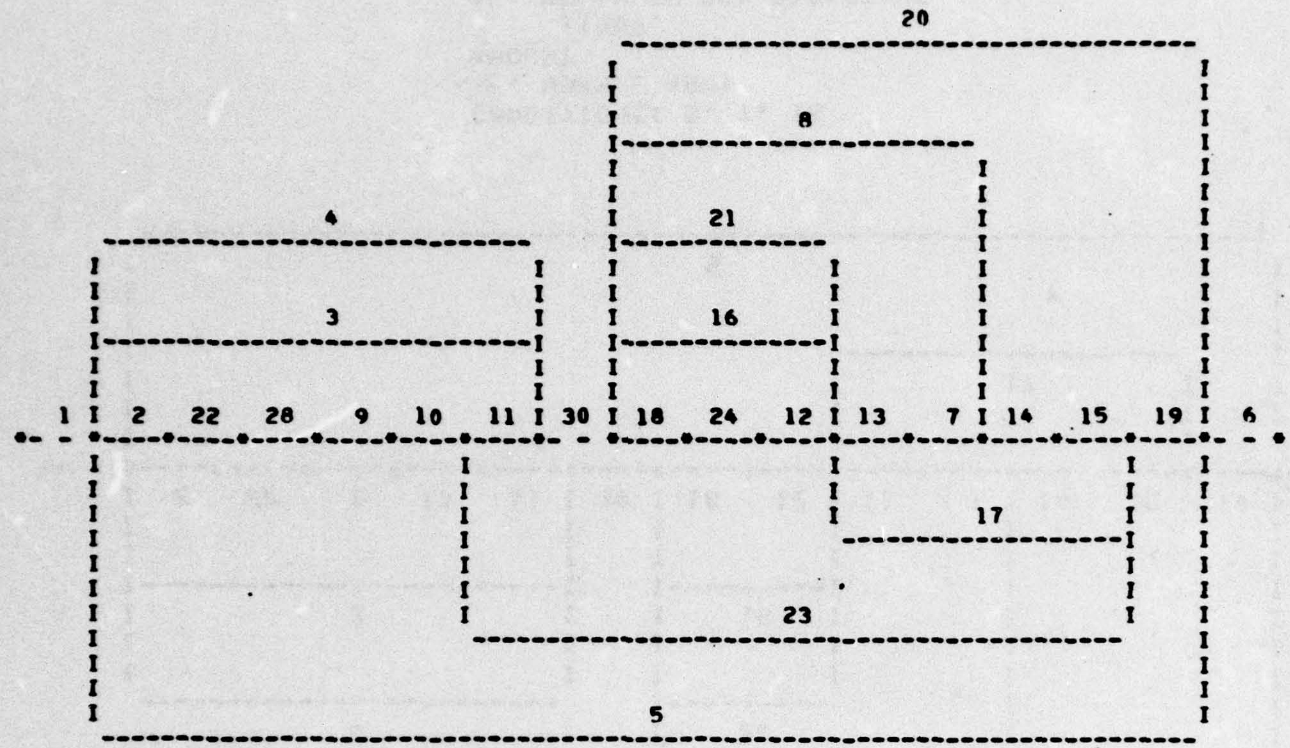
CONDITIONS: 5, 7, 14
AE, NORMAL ARMY
AMOUNT
11000.



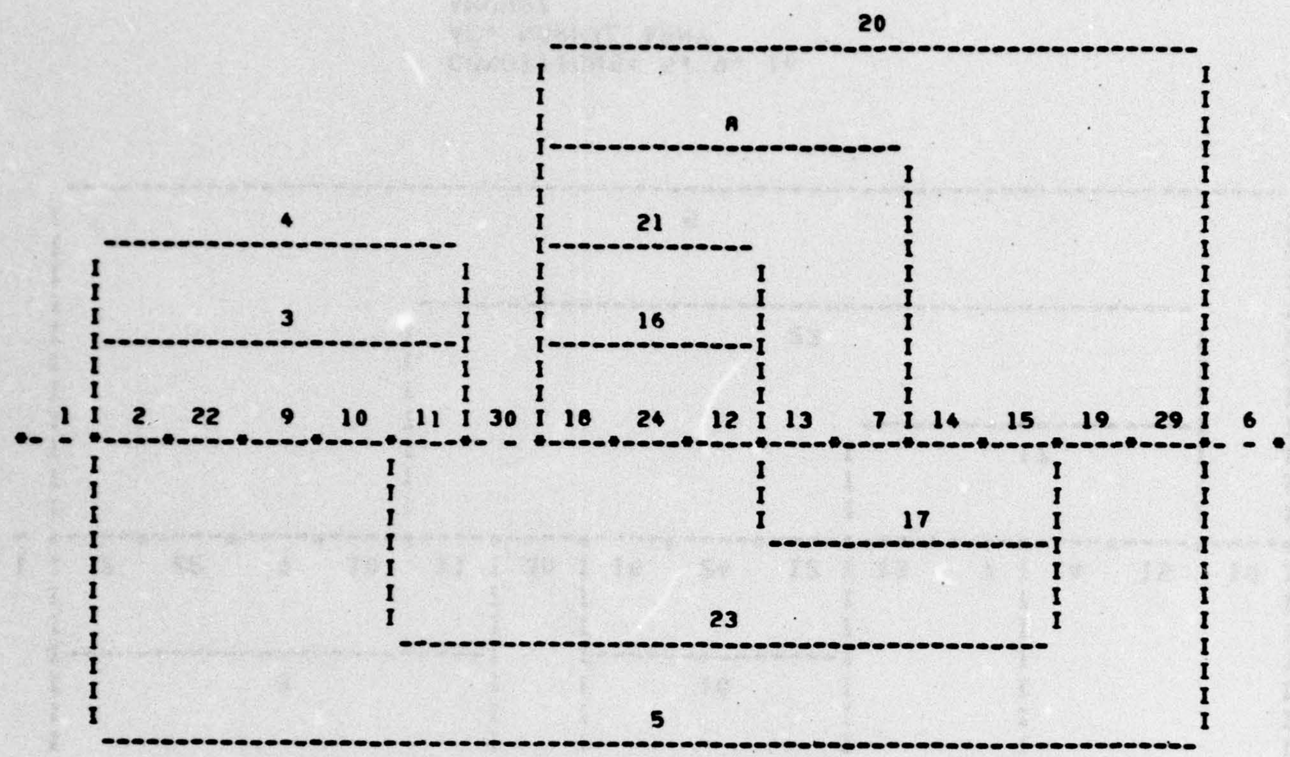
CONDITIONS: 5, 7, 15
AE, NORMAL ARMY
AMOUNT
11000.
AE, DELAY IN NOTICE TO PROCEED



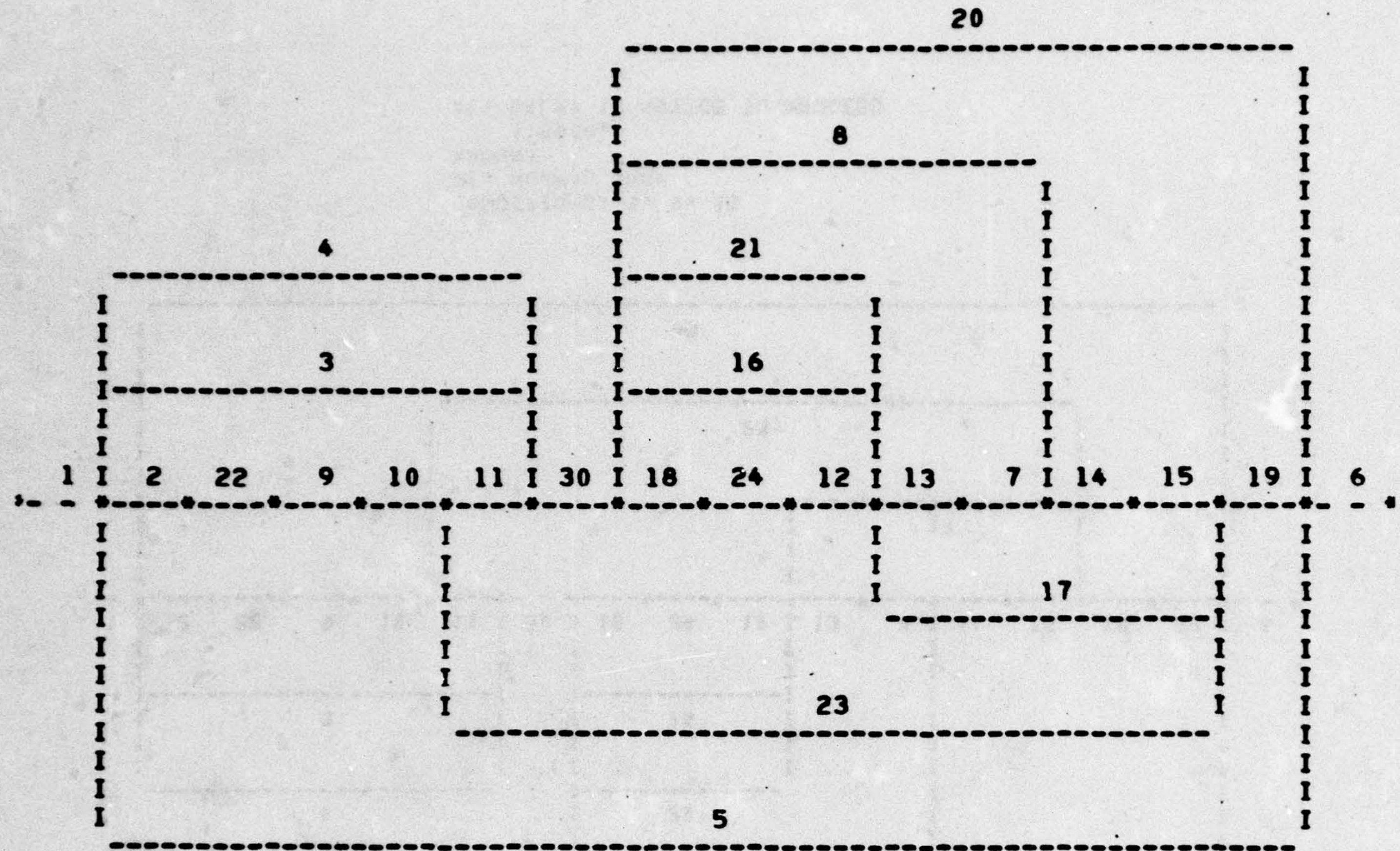
CONDITIONS: 5, 7, 16
AE, NORMAL ARMY
AMOUNT
11000.
AE, DELAY IN DES DIRECTIVE



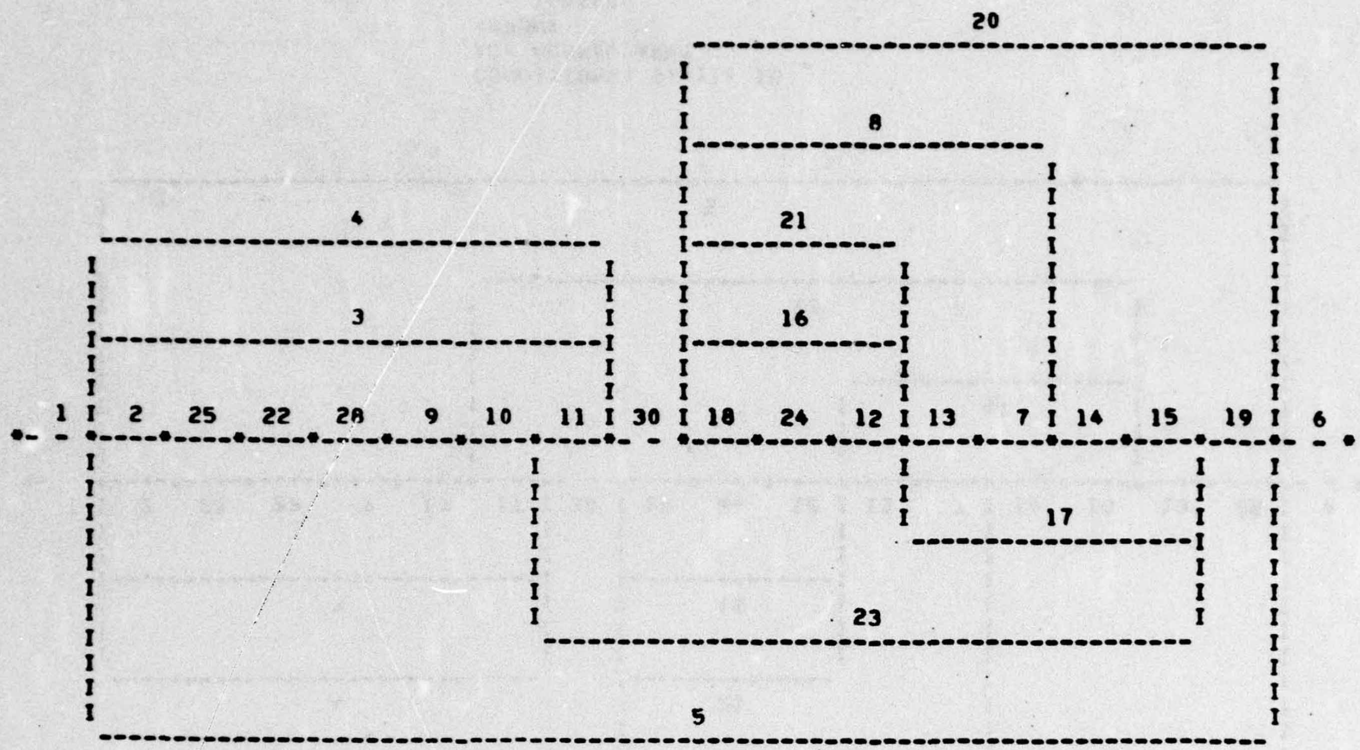
CONDITIONS: 5, 9, 14
AE, NORMAL ARMY
AMOUNT
110000.



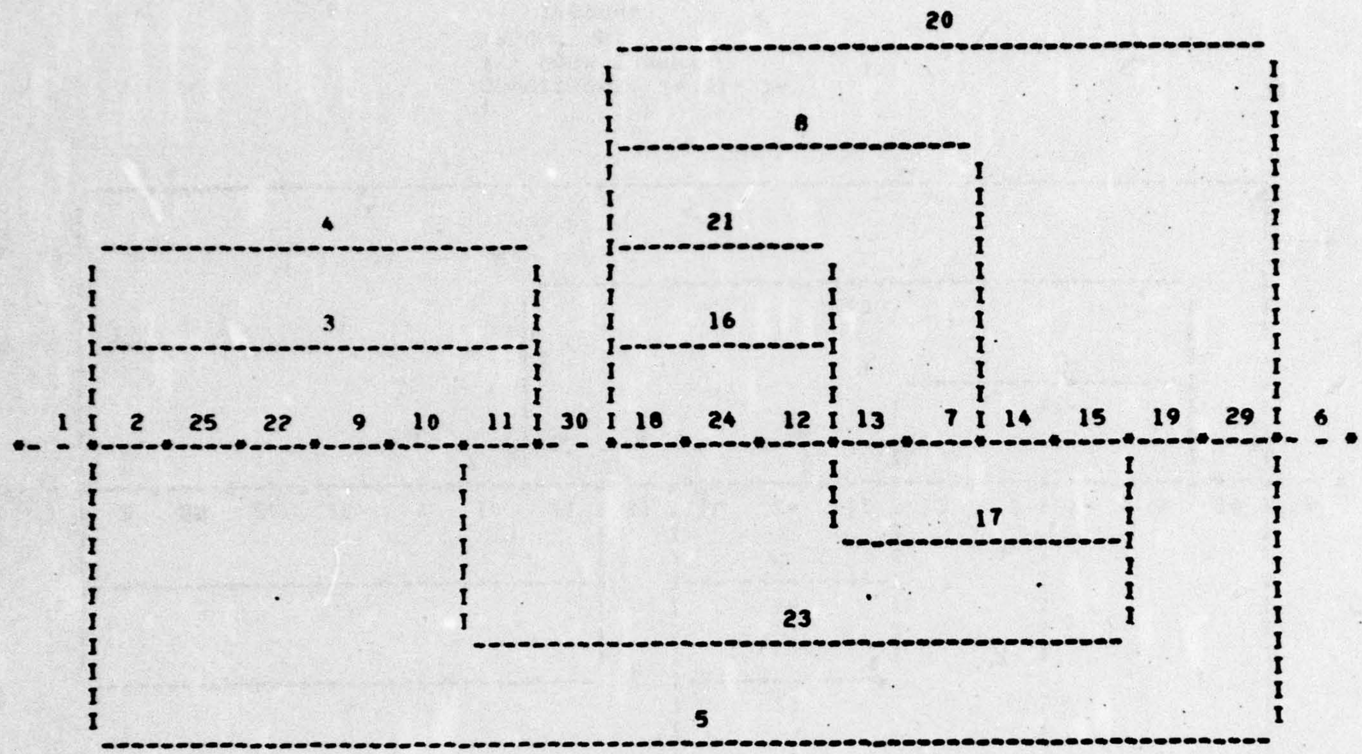
CONDITIONS: 5, 9, 15
AE, NORMAL ARMY
AMOUNT
110000.
AE, DELAY IN NOTICE TO PROCEED



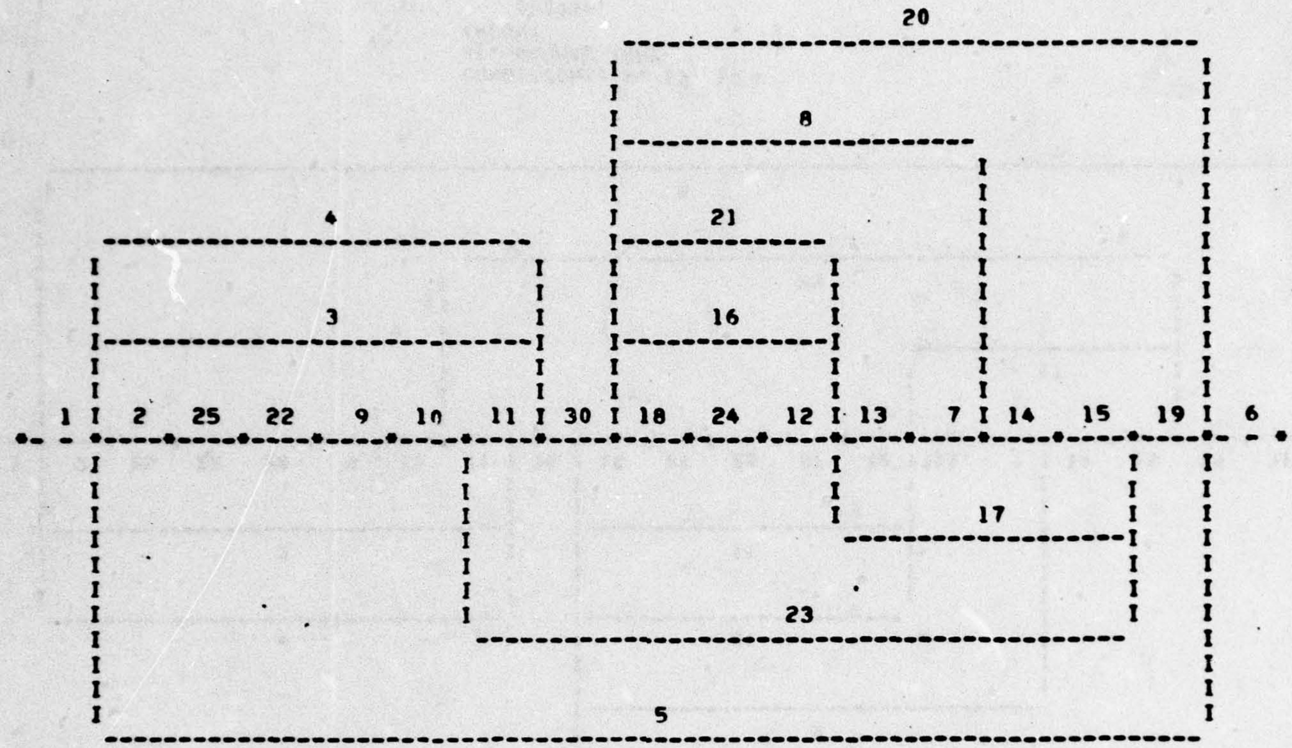
CONDITIONS: 5, 9, 16
AE, NORMAL ARMY
AMOUNT
110000.
AE, DELAY IN DES DIRECTIVE



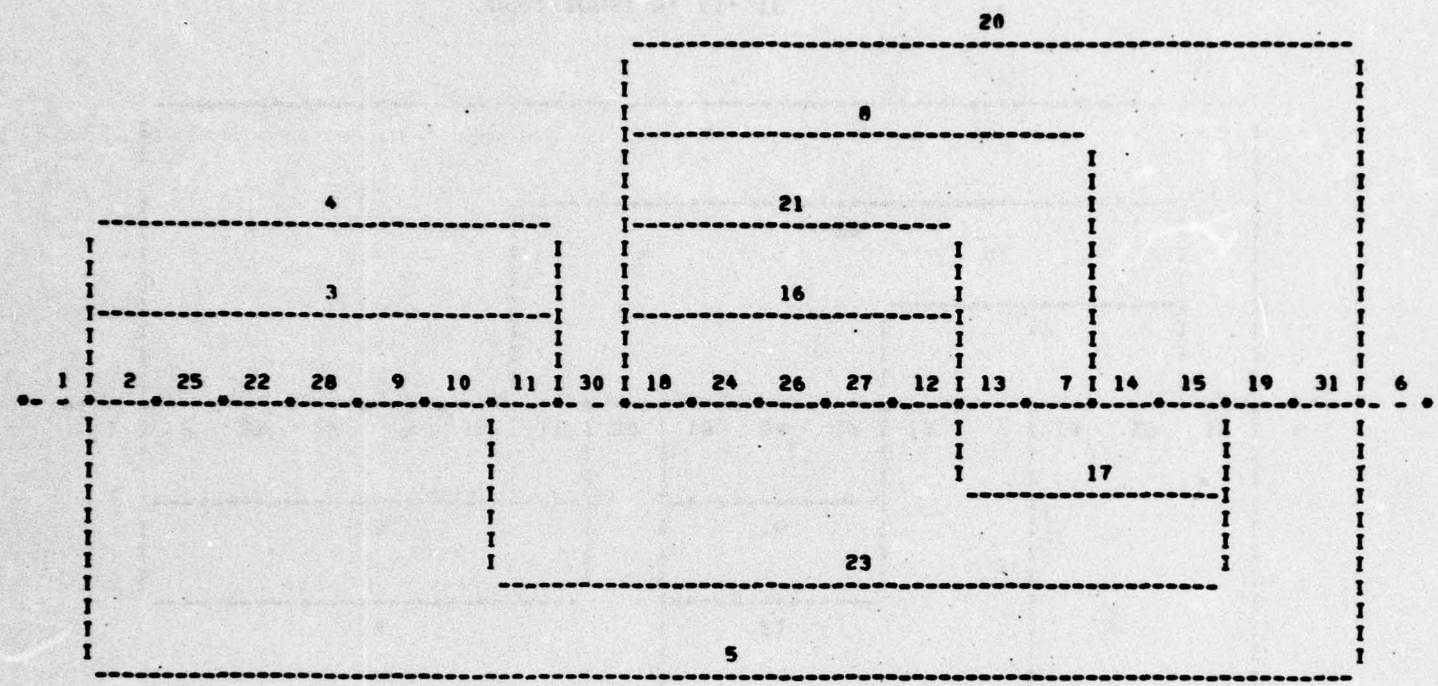
CONDITIONS: 5, 11, 14
AE, NORMAL ARMY
AMOUNT
160000.



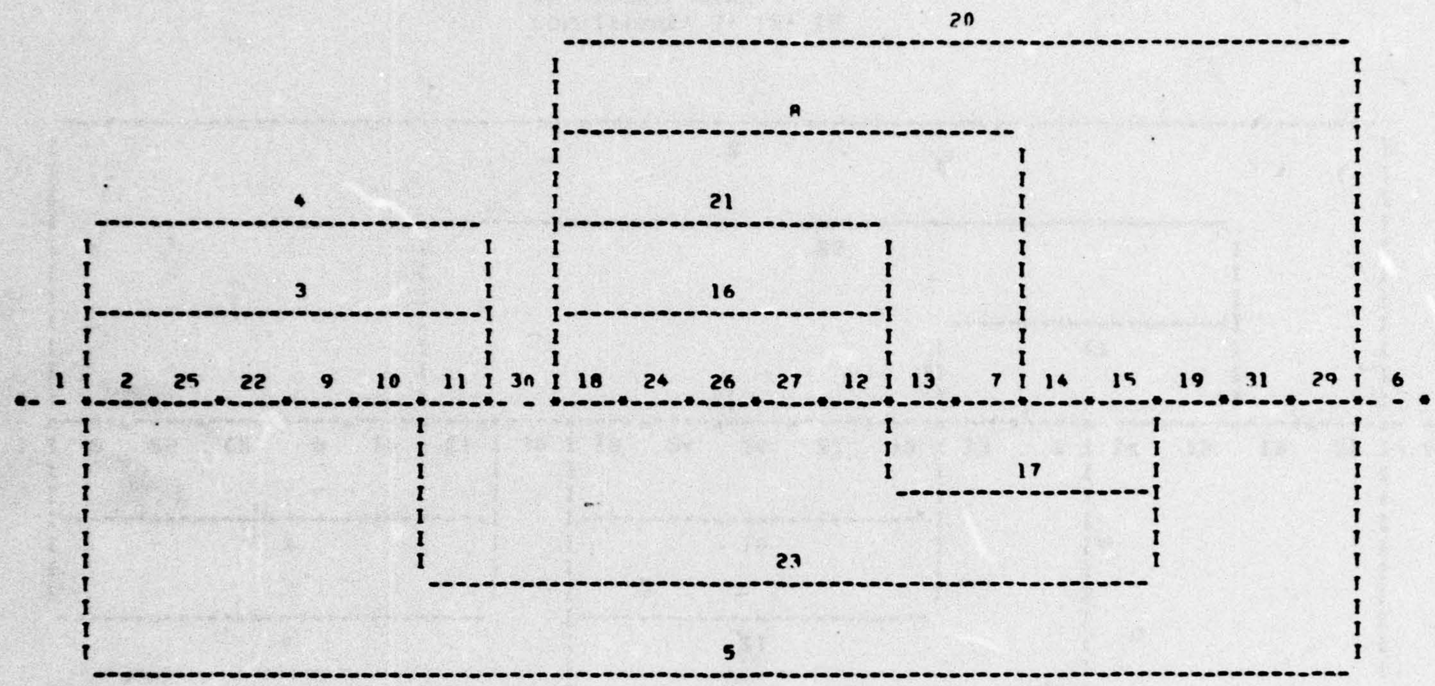
CONDITIONS: 5, 11, 15
AE, NORMAL ARMY
AMOUNT
160000.
AE, DELAY IN NOTICE TO PROCEED



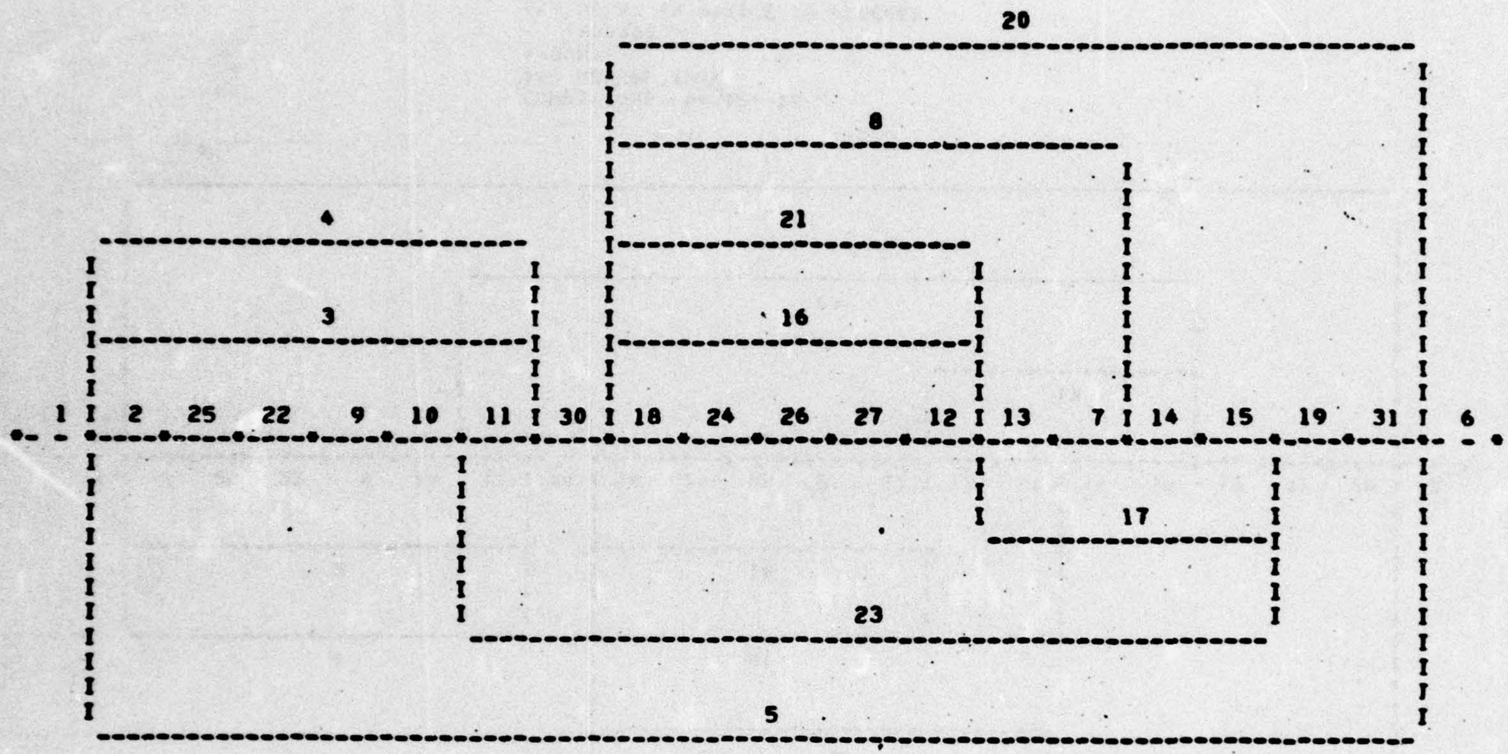
CONDITIONS: 5, 11, 16
AE, NORMAL ARMY
AMOUNT
160000.
AE, DELAY IN DES DIRECTIVE



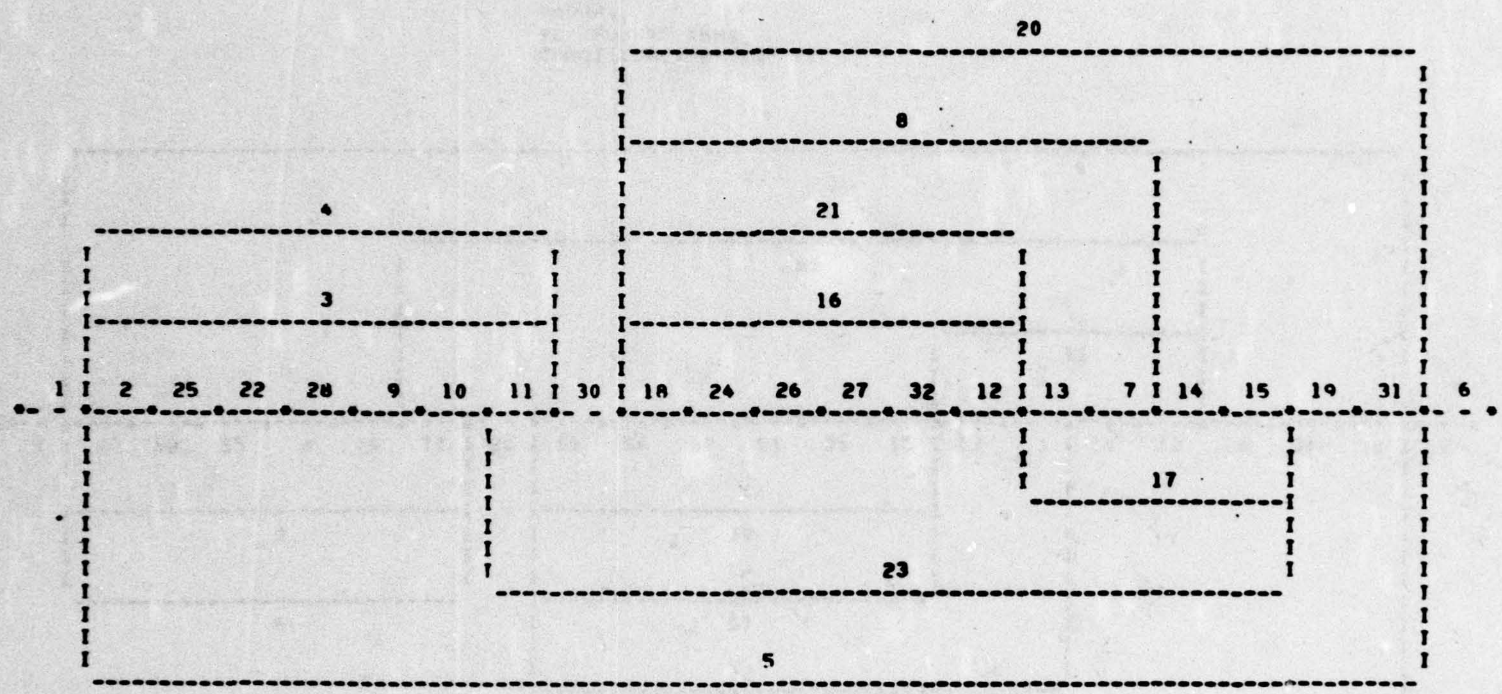
CONDITIONS: 5, 12, 14
AE, NORMAL ARMY
AMOUNT
600000.



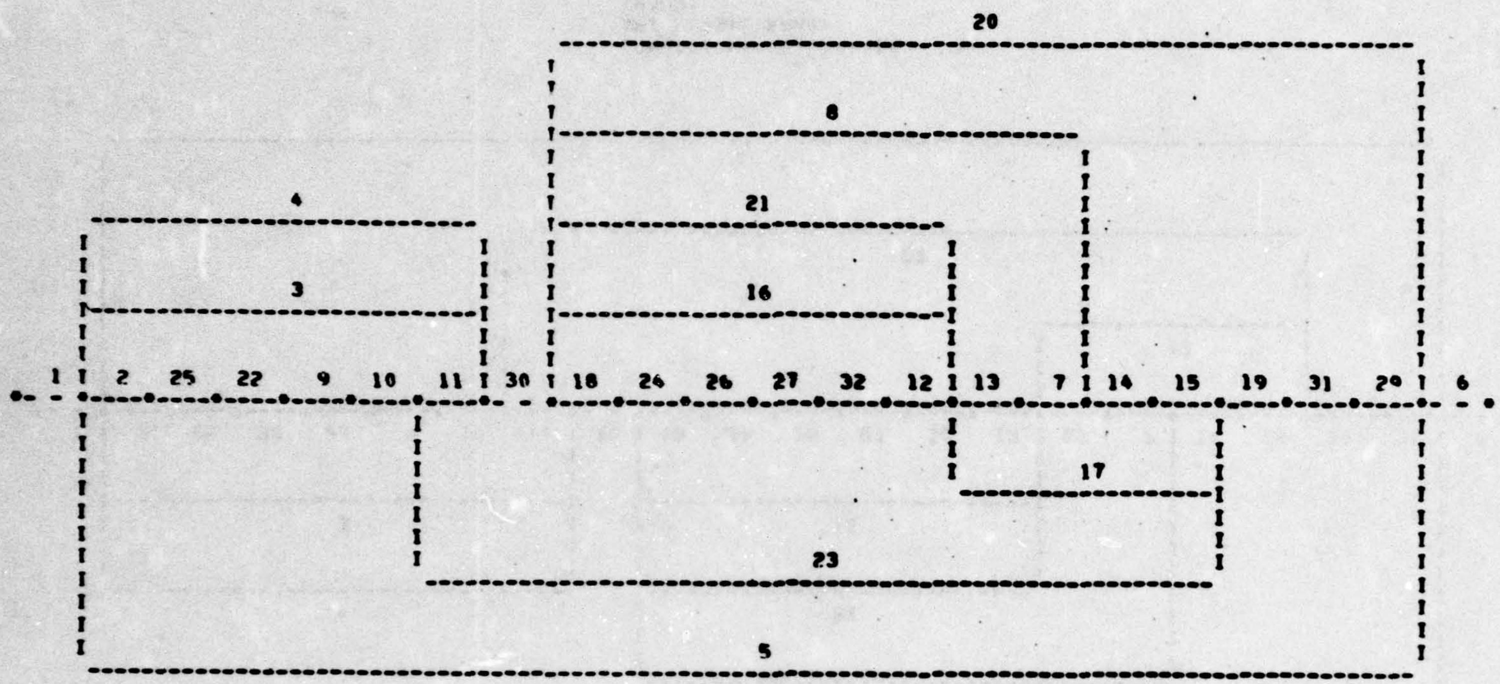
CONDITIONS: 5, 12, 15
AE, NORMAL ARMY
AMOUNT
    600000.
AE, DELAY IN NOTICE TO PROCEED



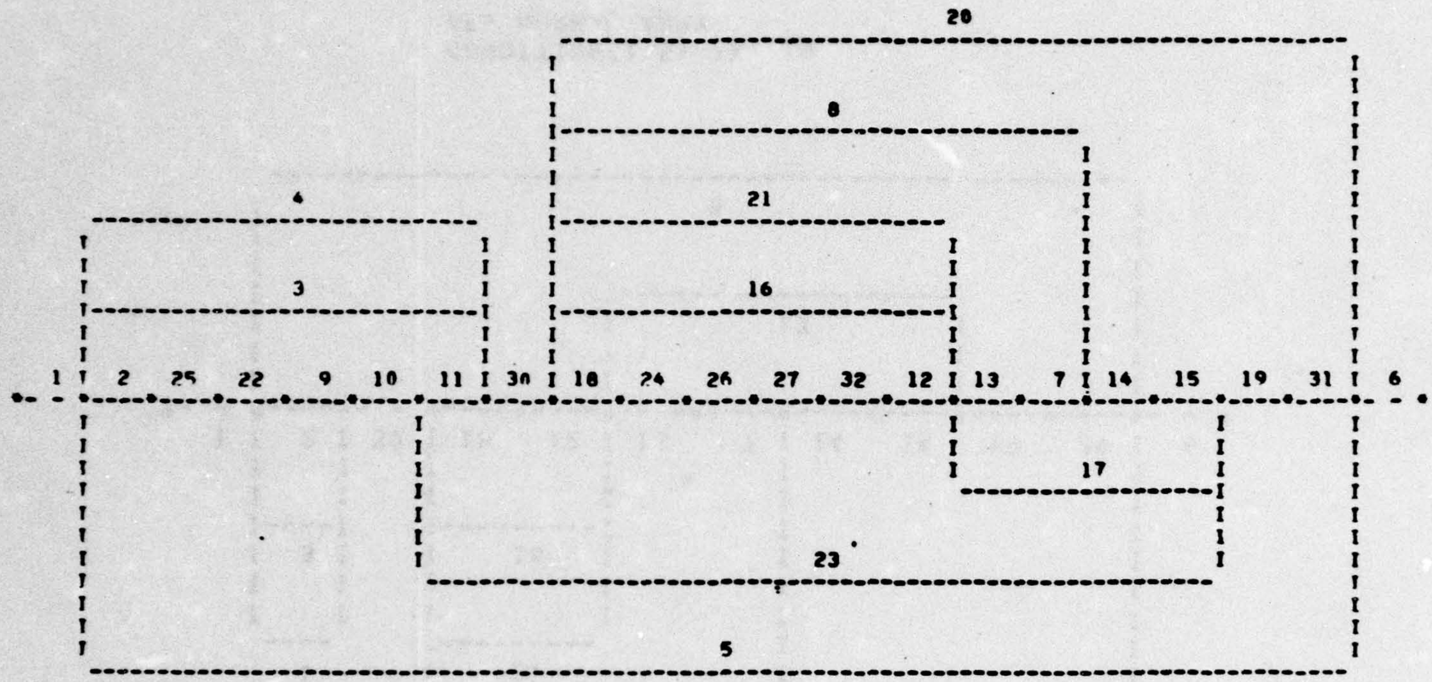
CONDITIONS: 5, 12, 16
AE, NORMAL ARMY
AMOUNT
    600000.
AE, DELAY IN DES DIRECTIVE



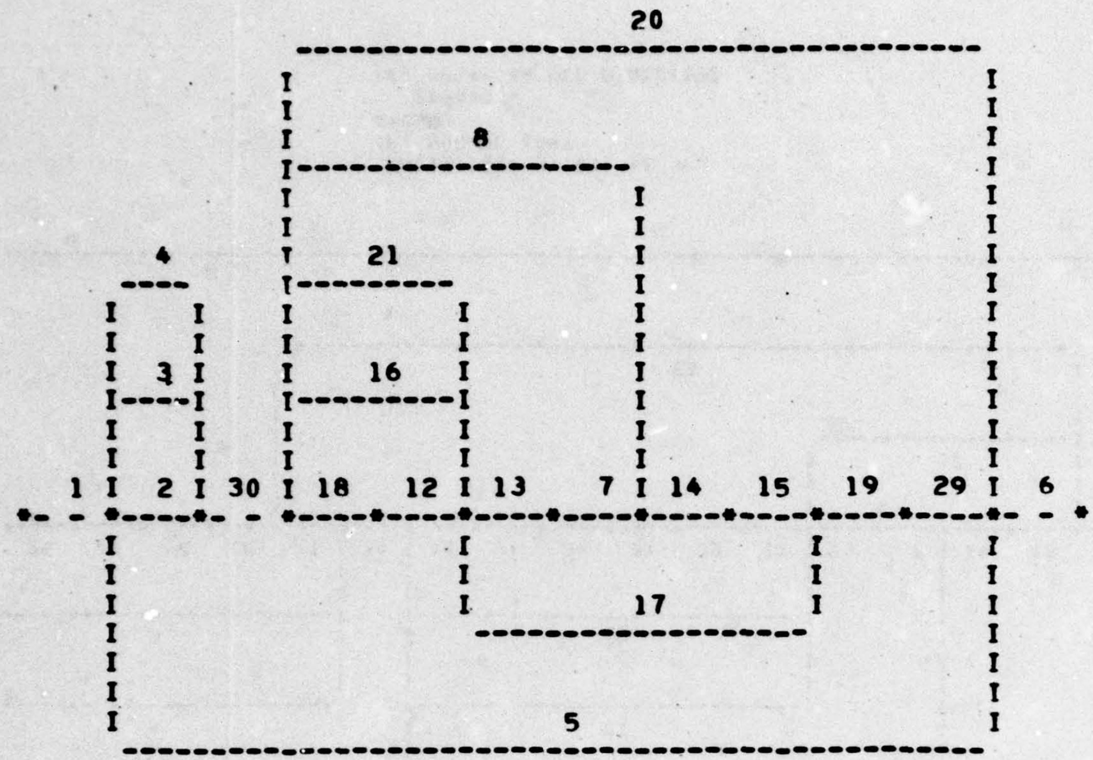
CONDITIONS: 5, 13, 14
AE, NORMAL ARMY
AMOUNT
2000000.



CONDITIONS: 5, 13, 15
AF, NORMAL ARMY
AMOUNT
2000000.
AE, DELAY IN NOTICE TO PROCEED

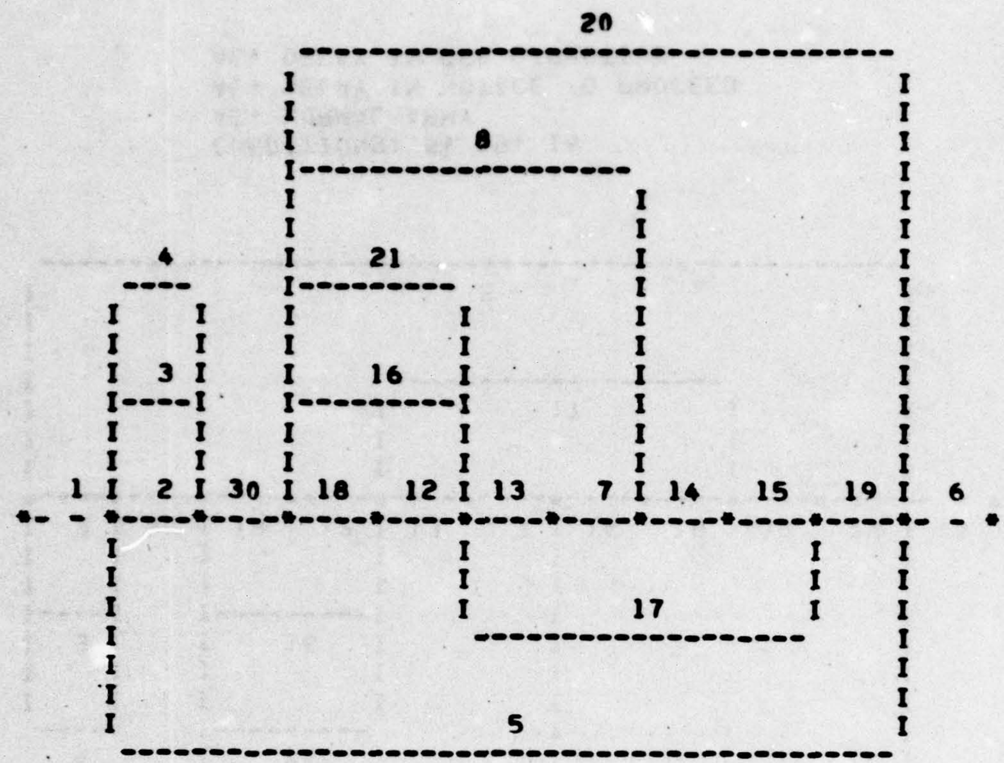


CONDITIONS: 5, 13, 16
AE. NORMAL ARMY
AMOUNT
2000000.
AE. DELAY IN DES DIRECTIVE



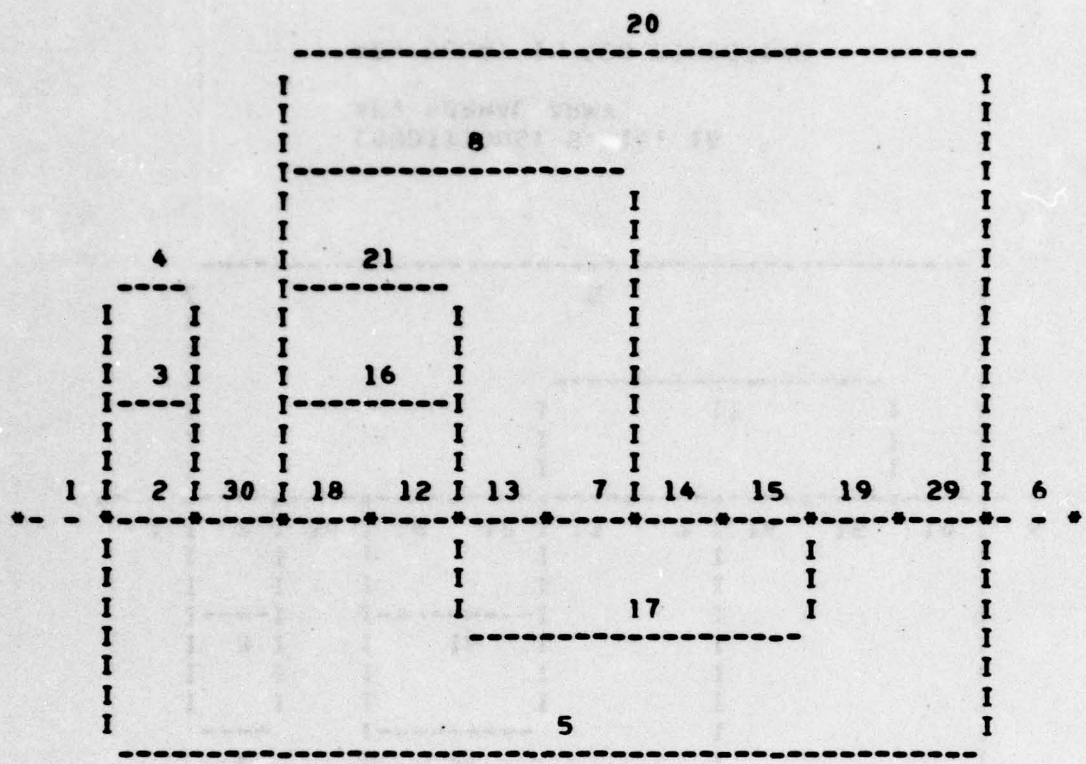
CONDITIONS: 5, 14, 15
AE, NORMAL ARMY

AE, DELAY IN NOTICE TO PROCEED

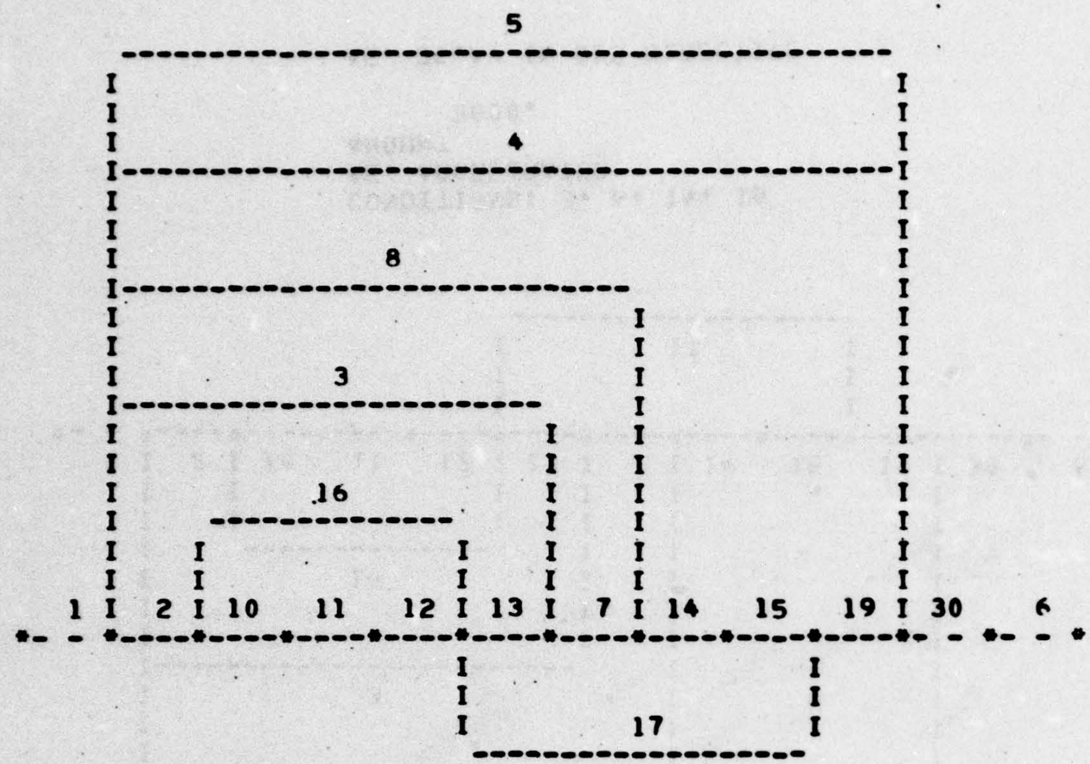


CONDITIONS: 5, 14, 16
AE, NORMAL ARMY

AE, DELAY IN DES DIRECTIVE

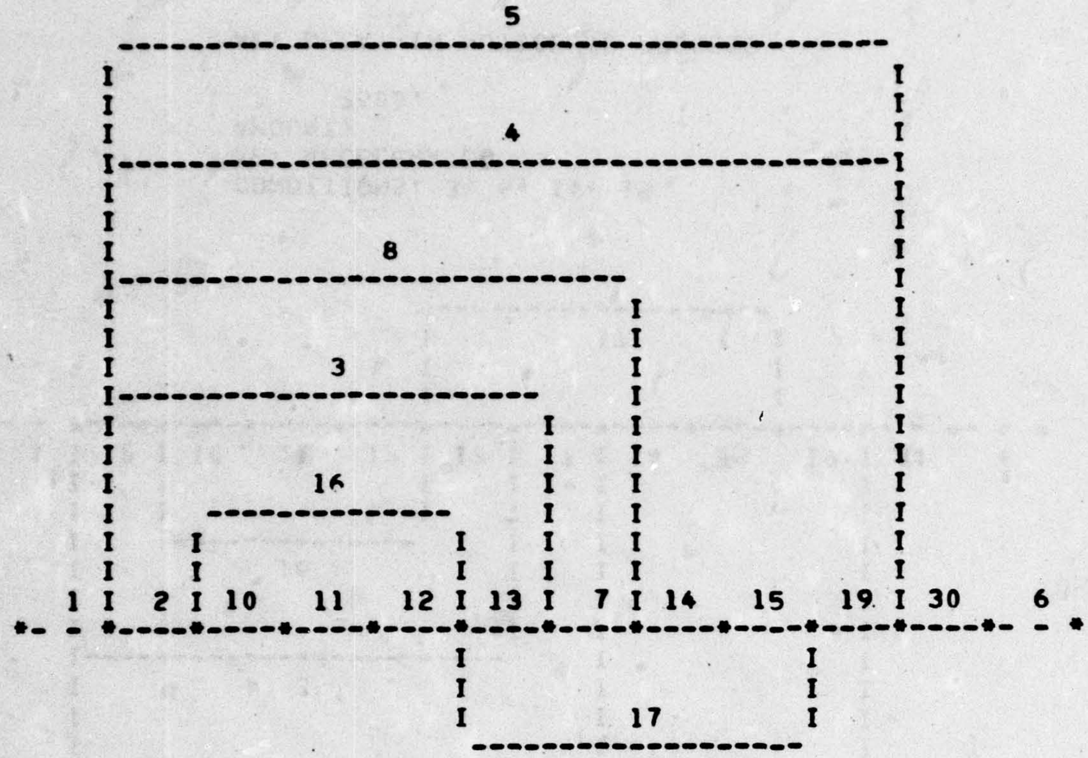


CONDITIONS: 5, 15, 16
AE, NORMAL ARMY
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



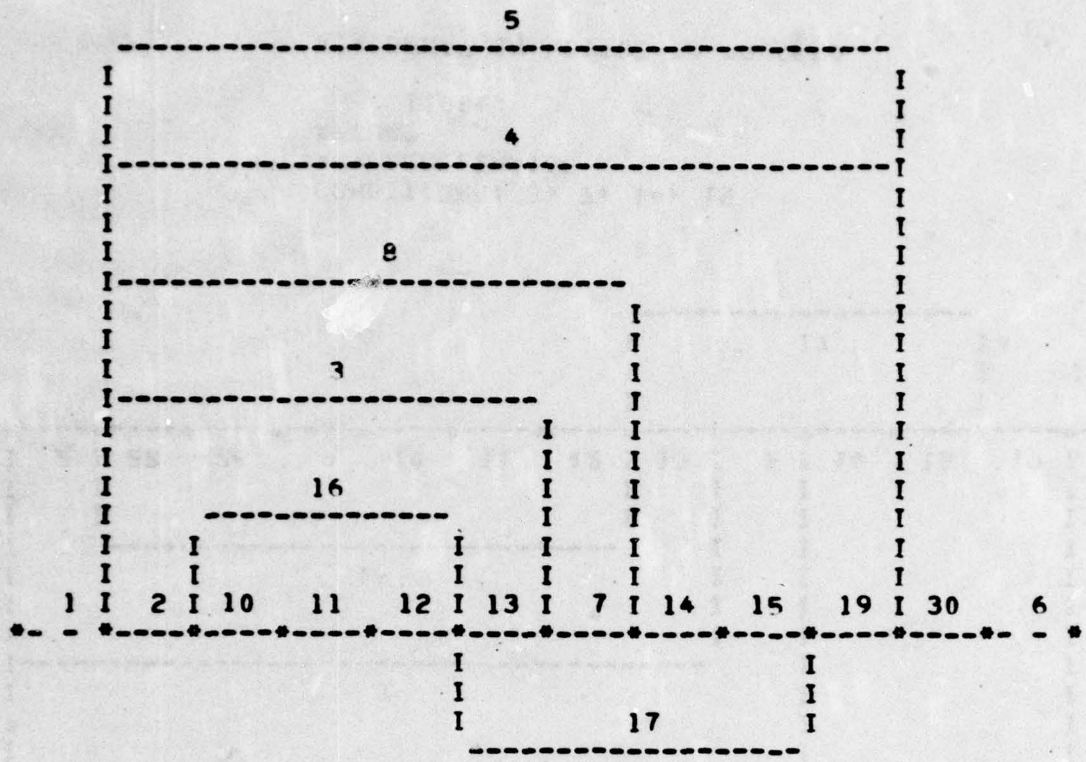
CONDITIONS: 3, 6, 14, 15
AE, ACCELERATED
AMOUNT
2600.

AE, DELAY IN NOTICE TO PROCEED

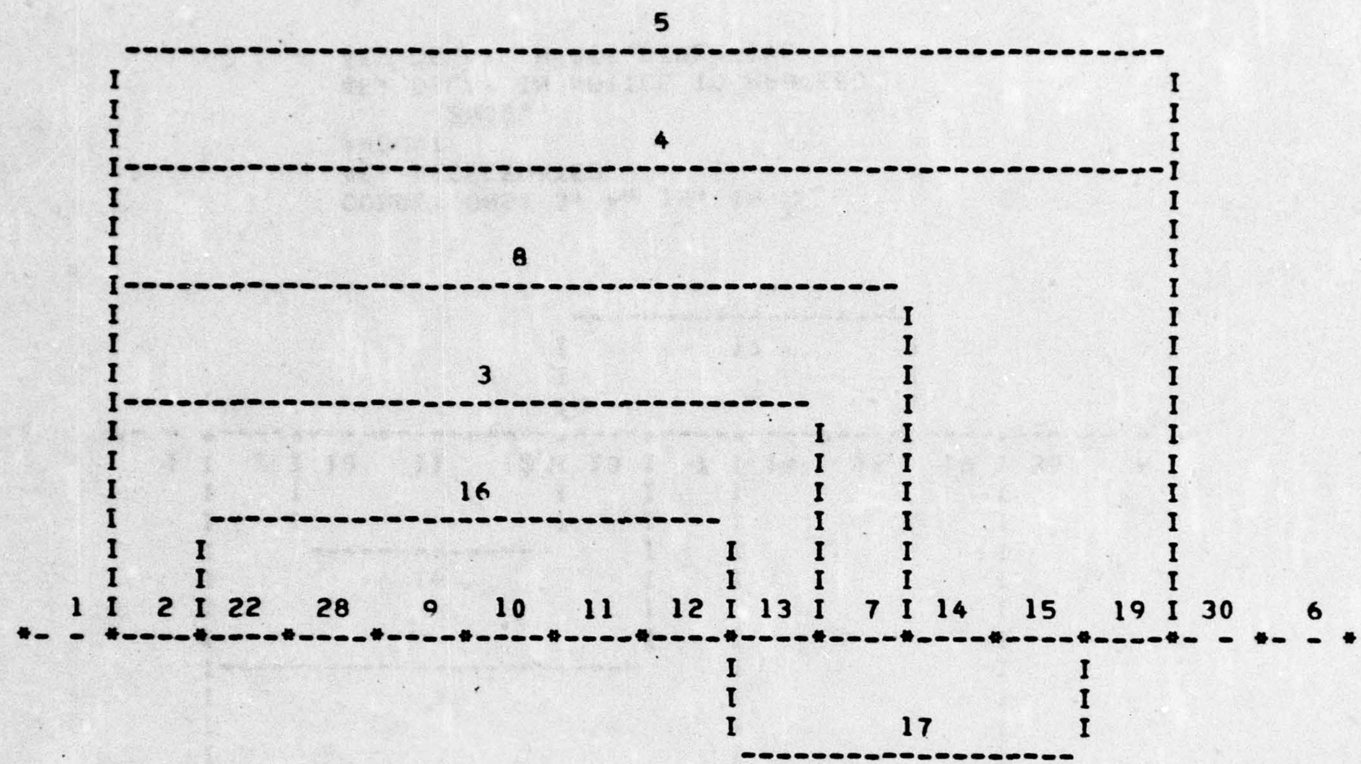


CONDITIONS: 3, 6, 14, 16
AE, ACCELERATED
AMOUNT
2600.

AE, DELAY IN DES DIRECTIVE

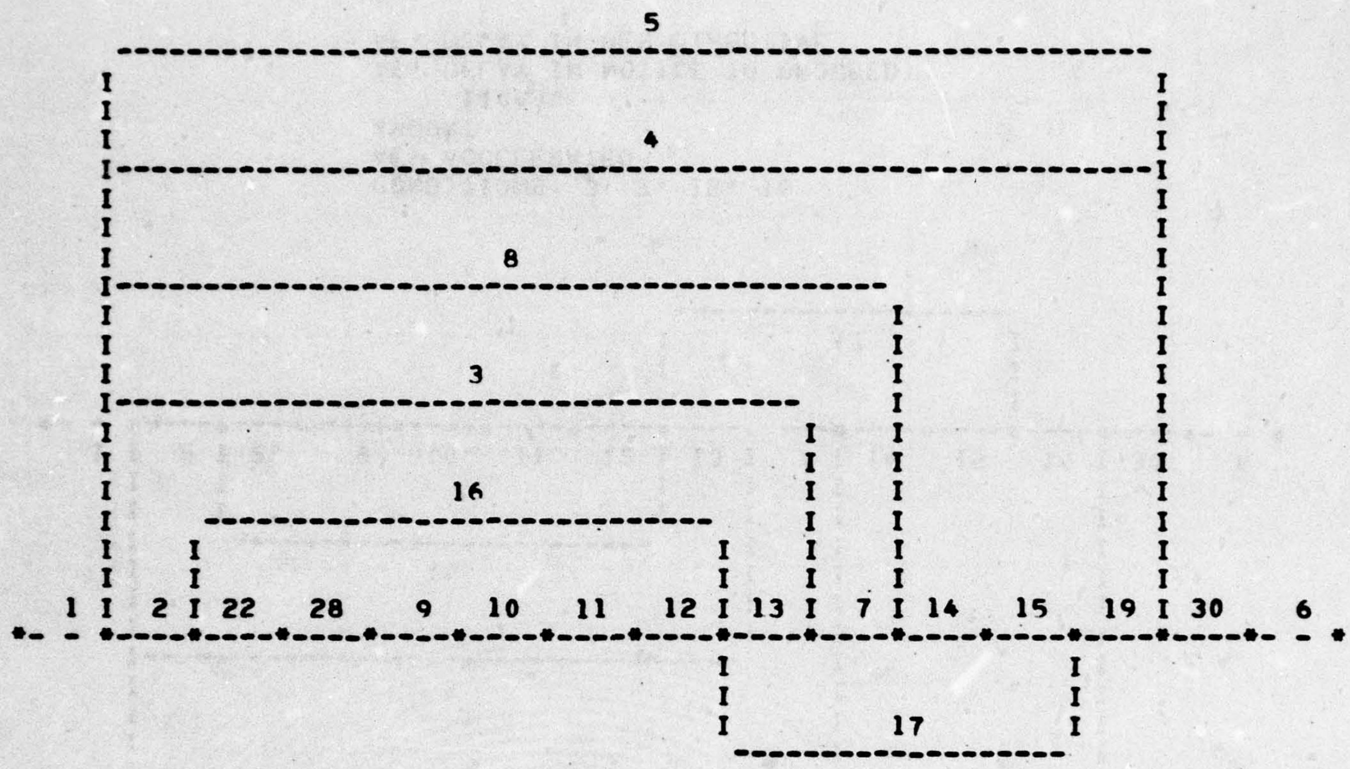


CONDITIONS: 3, 6, 15, 16
AE, ACCELERATED
AMOUNT
2600.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



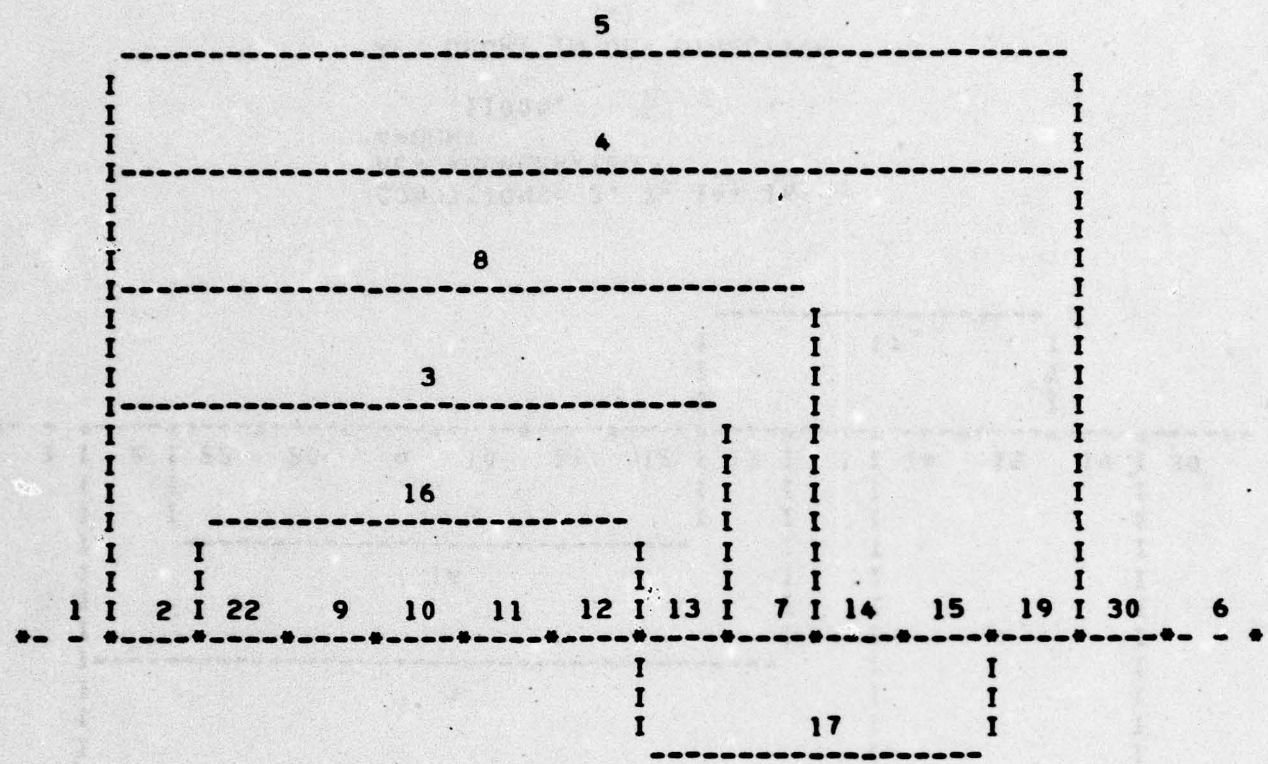
CONDITIONS: 3, 7, 14, 15
AE, ACCELERATED
AMOUNT
11000.

AE, DELAY IN NOTICE TO PROCEED

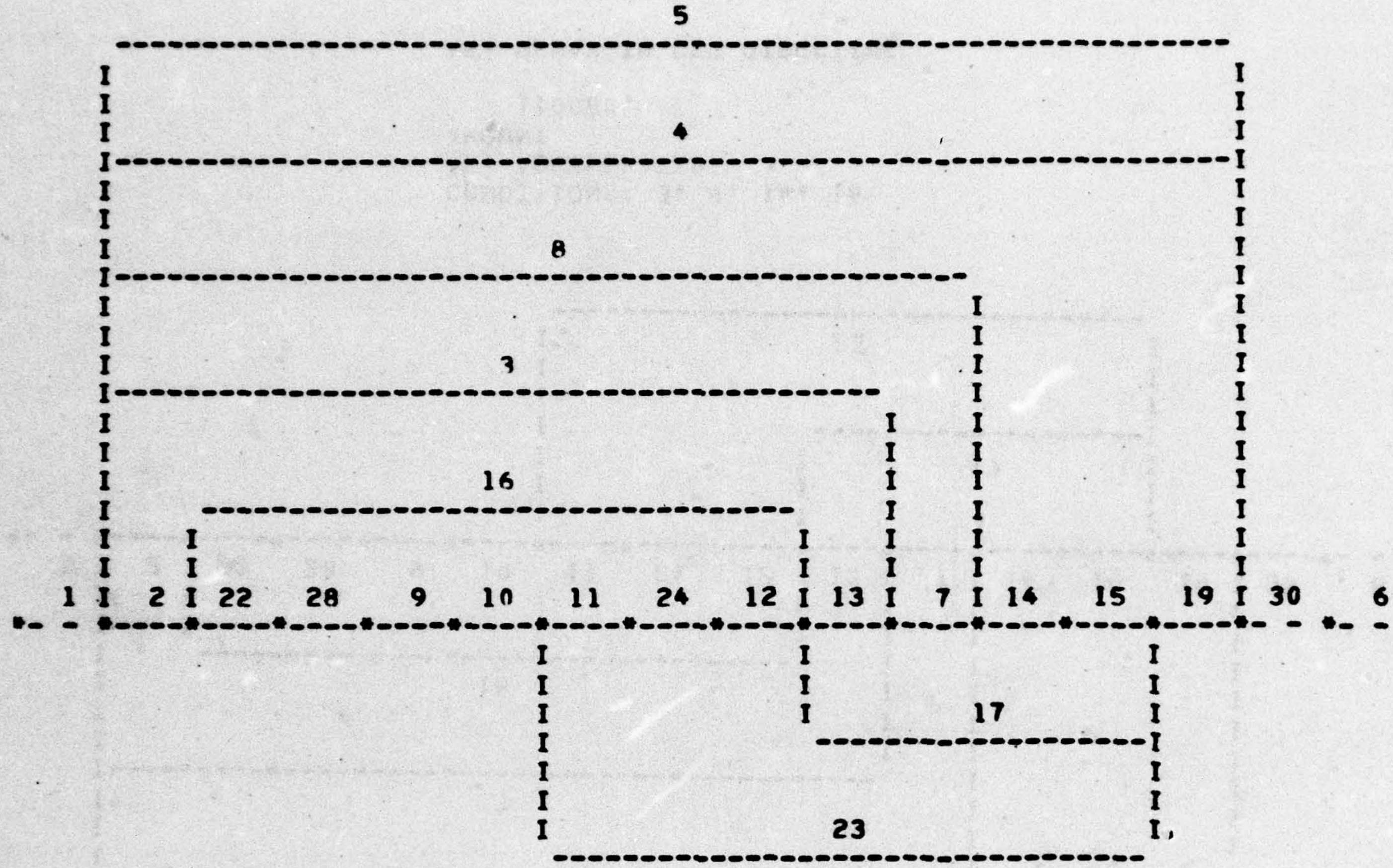


CONDITIONS: 3, 7, 14, 16
AE, ACCELERATED
AMOUNT
11000.

AE, DELAY IN DES DIRECTIVE

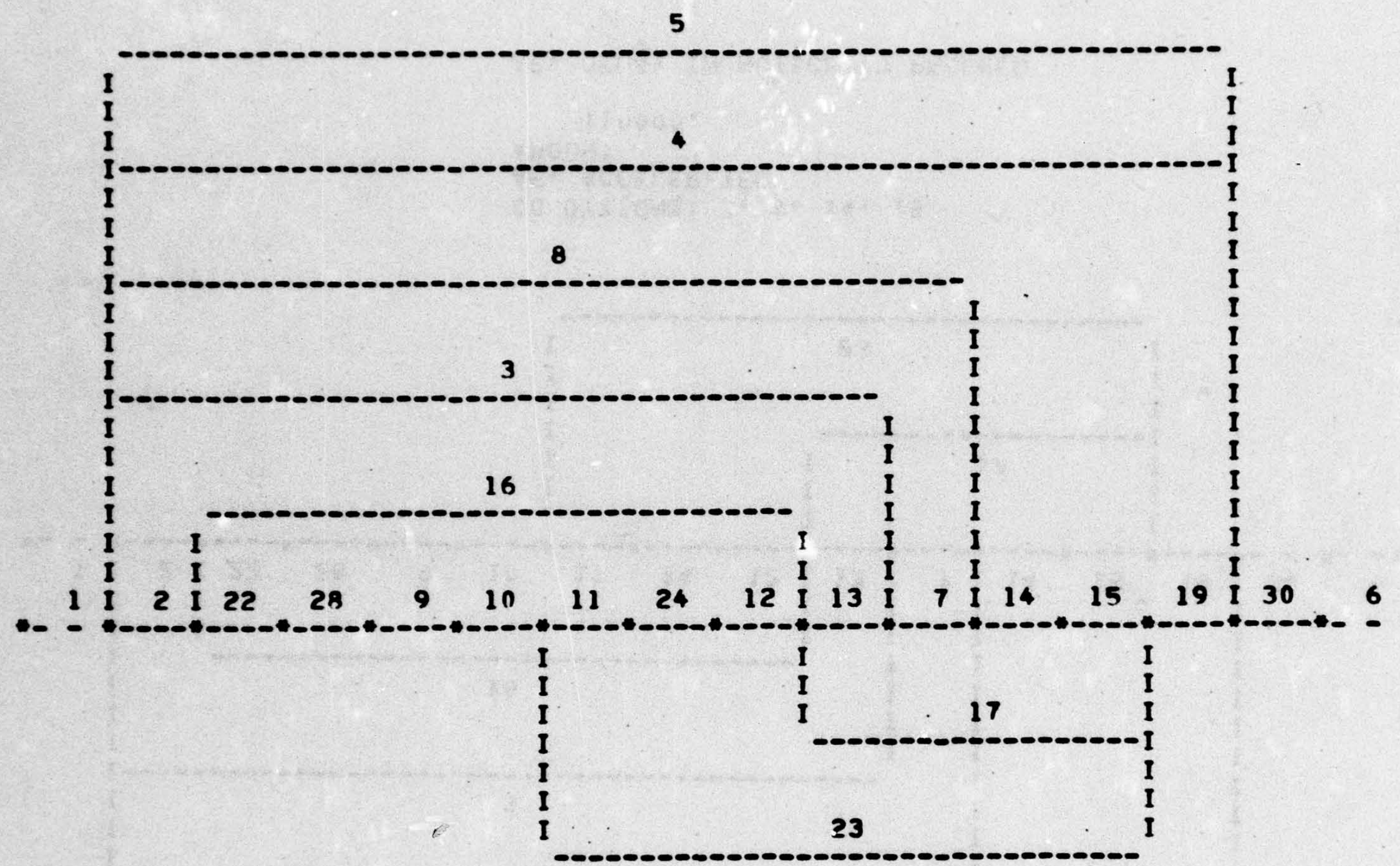


CONDITIONS: 3, 7, 15, 16
AE, ACCELERATED
AMOUNT
11000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



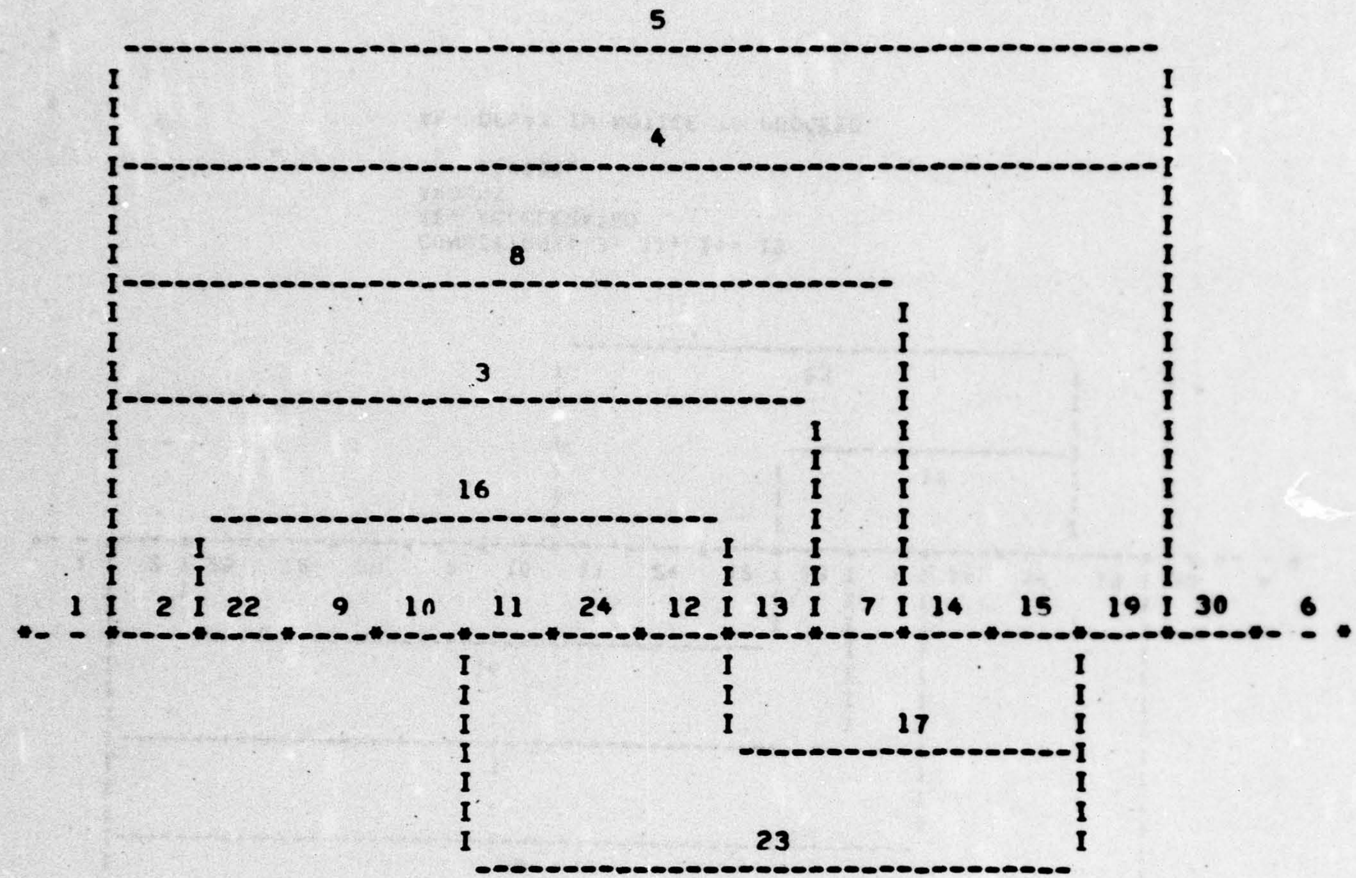
CONDITIONS: 3, 9, 14, 15
AE, ACCELERATED
AMOUNT
110000.

AE, DELAY IN NOTICE TO PROCEED

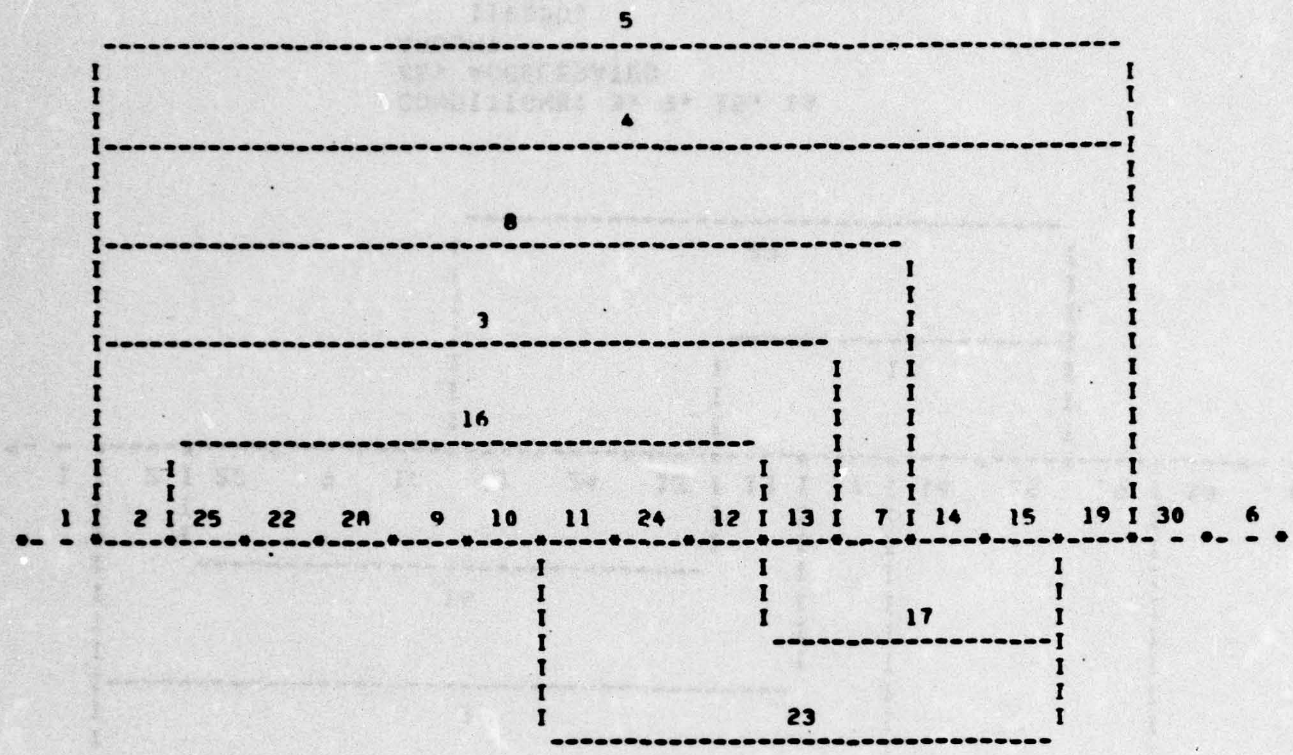


CONDITIONS: 3, 9, 14, 16
AE. ACCELERATED
AMOUNT
110000.

AE. DELAY IN DES DIRECTIVE

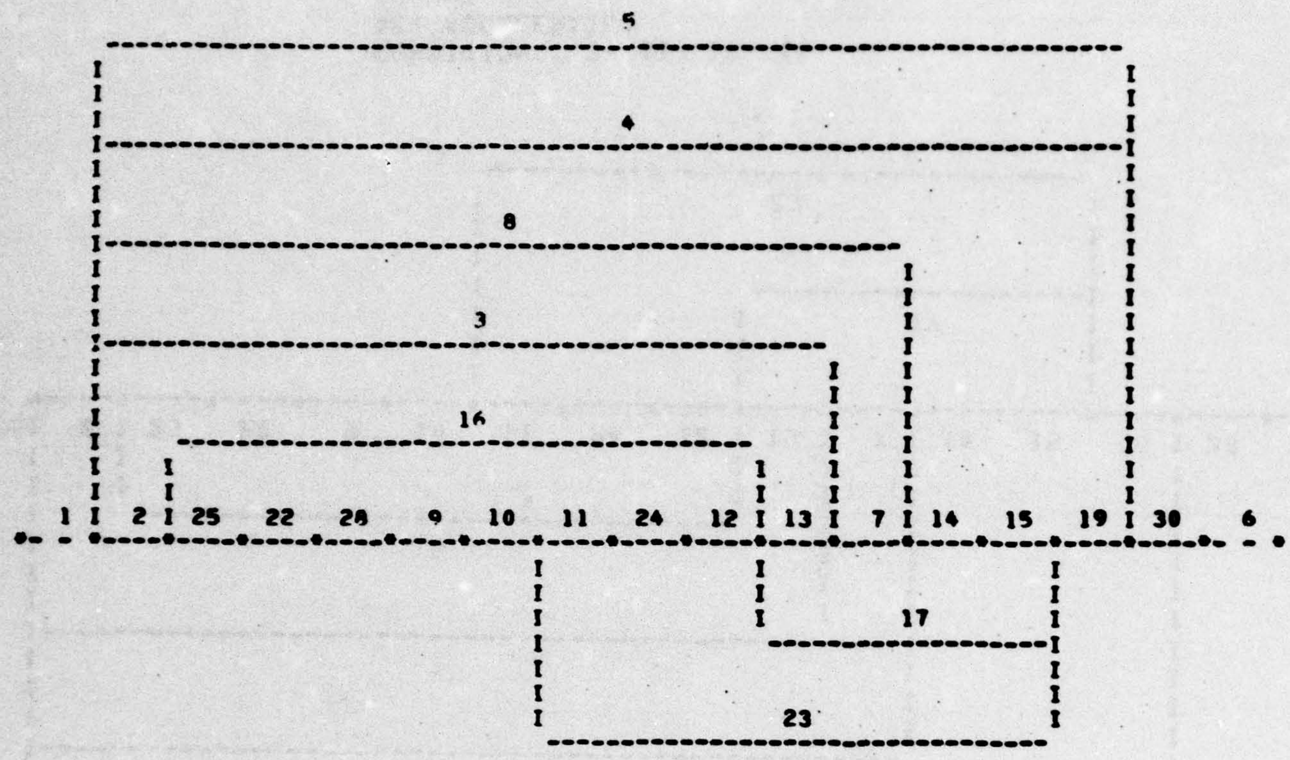


CONDITIONS: 3, 9, 15, 16
AE, ACCELERATED
AMOUNT
    110000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



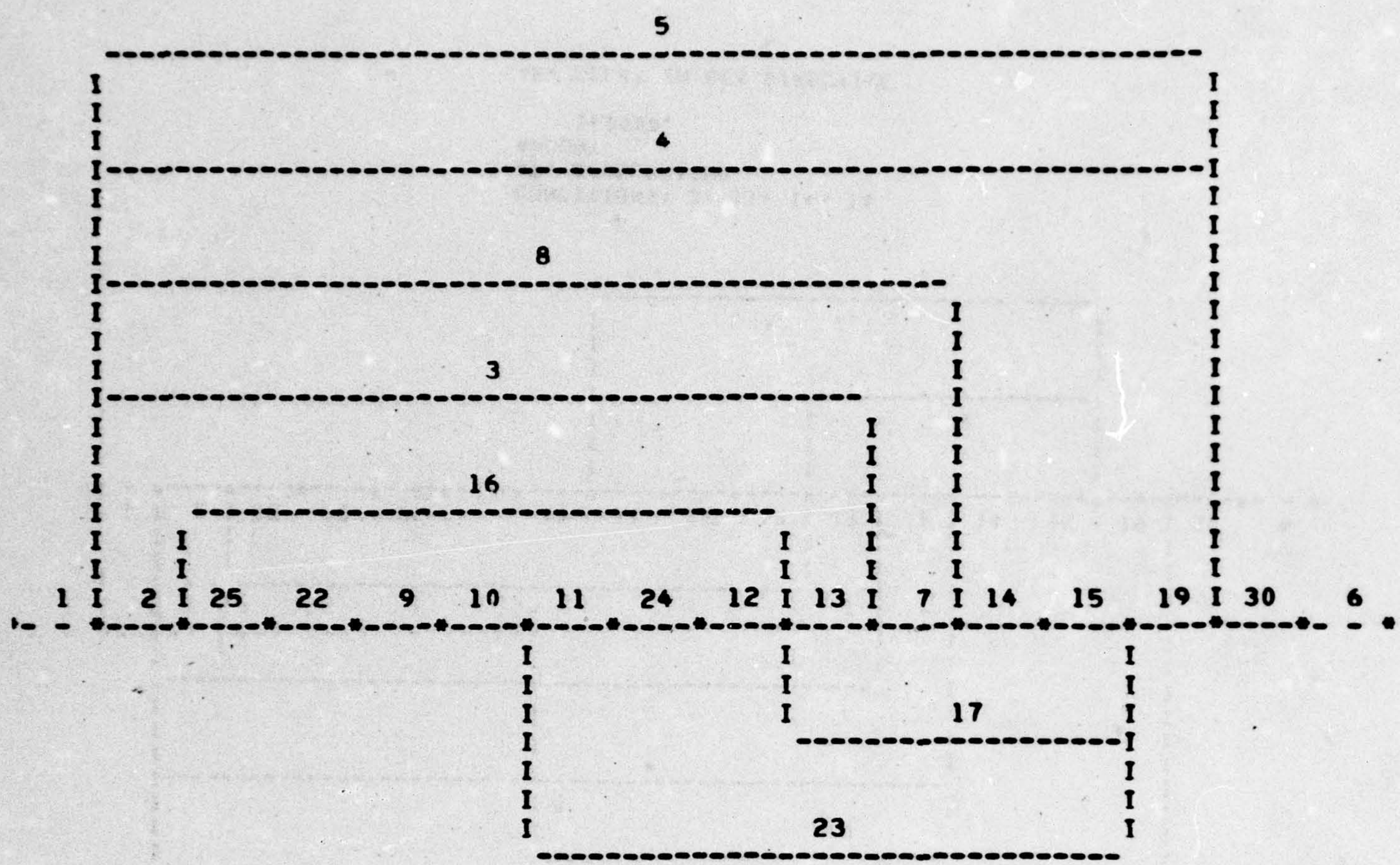
CONDITIONS: 3, 11, 14, 15
AE, ACCELERATED
AMOUNT
160000.

AE, DELAY IN NOTICE TO PROCEED.

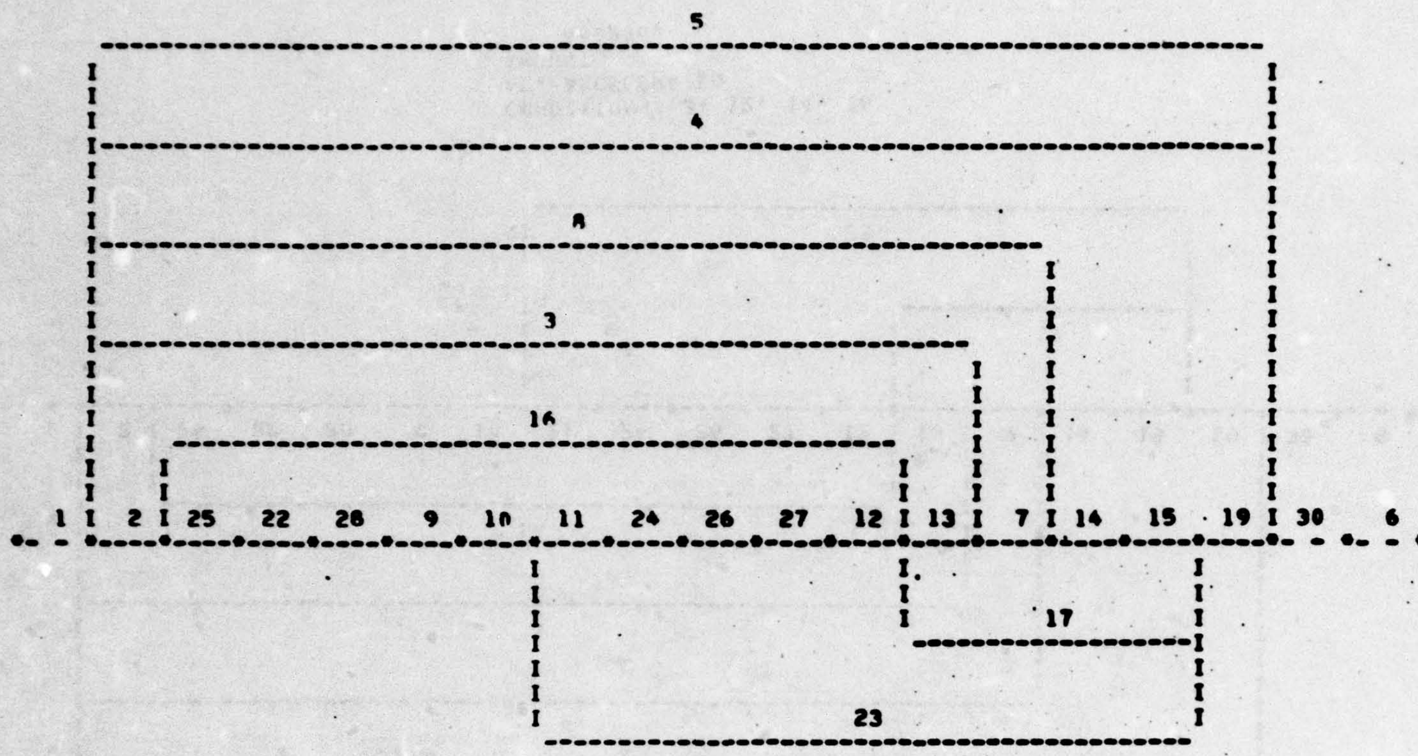


CONDITIONS: 3, 11, 14, 16
AE, ACCELERATED
AMOUNT
    160000.

AE, DELAY IN DES DIRECTIVE

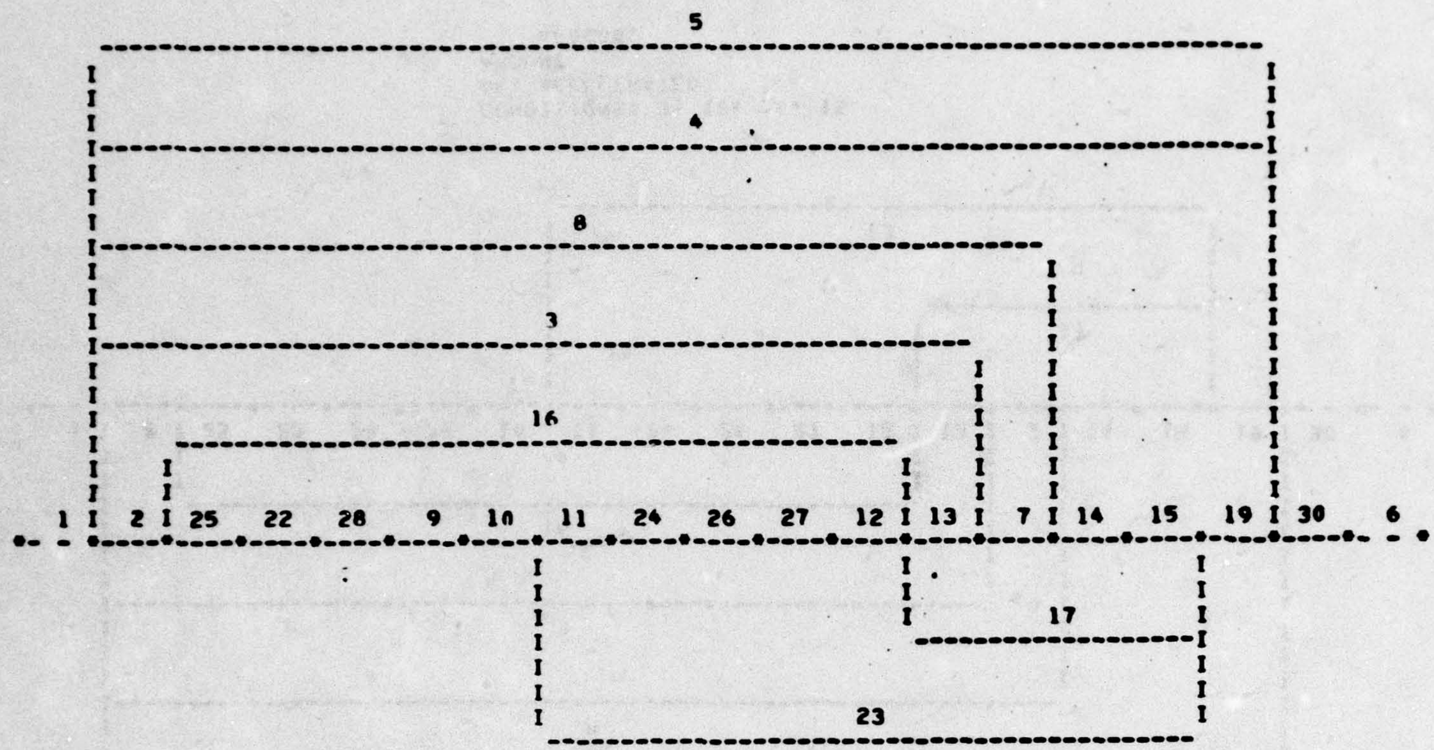


CONDITIONS: 3, 11, 15, 16
AE, ACCELERATED
AMOUNT
160000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



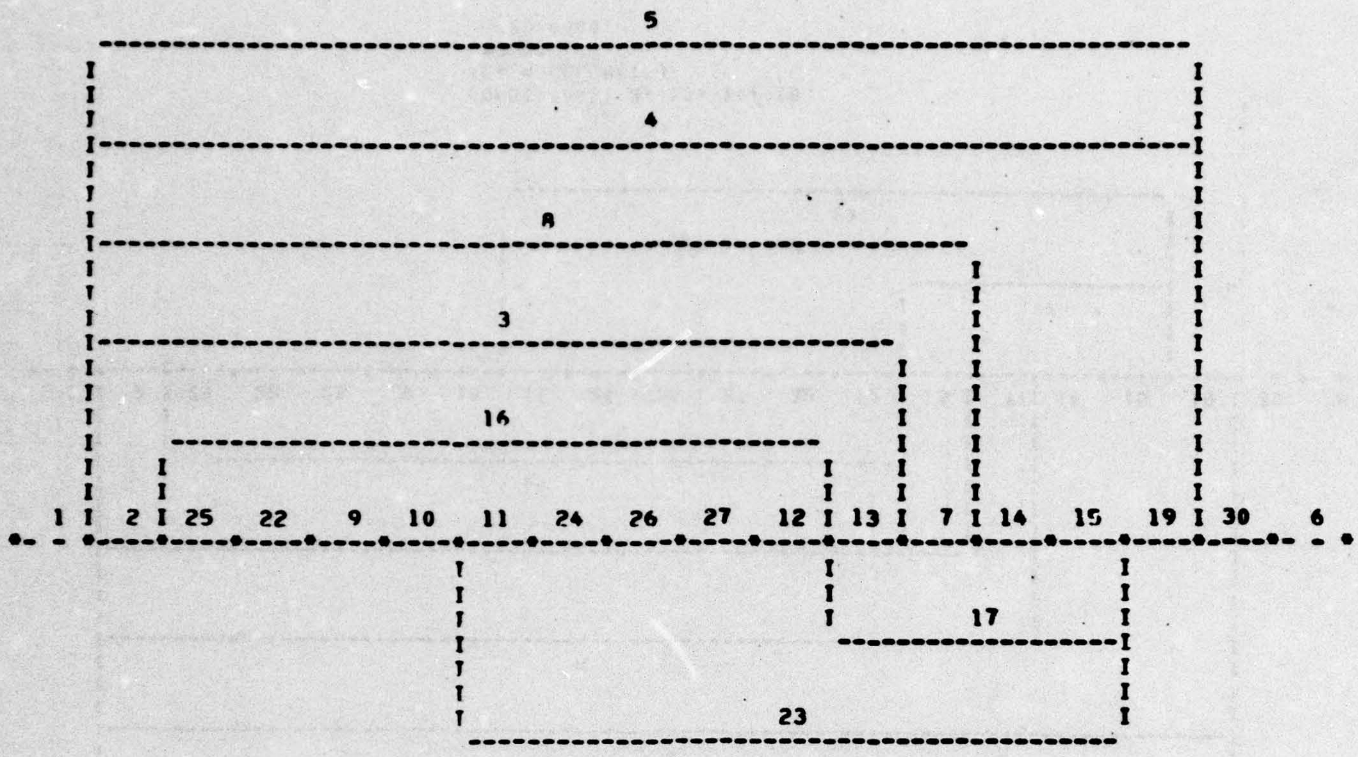
CONDITIONS: 3, 12, 14, 15
AE, ACCELERATED
AMOUNT
600000.

AE, DELAY IN NOTICE TO PROCEED

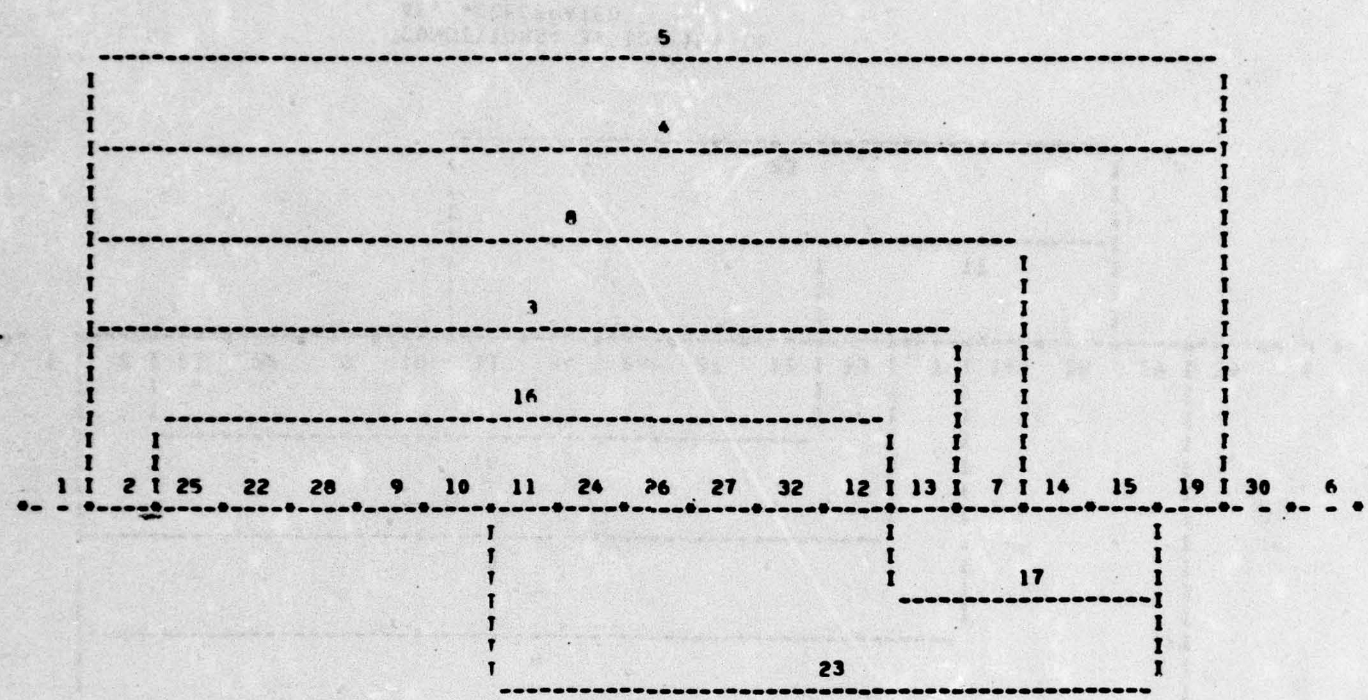


CONDITIONS: 3, 12, 14, 16
AE, ACCELERATED
AMOUNT
600000.

AE, DELAY IN DES DIRECTIVE

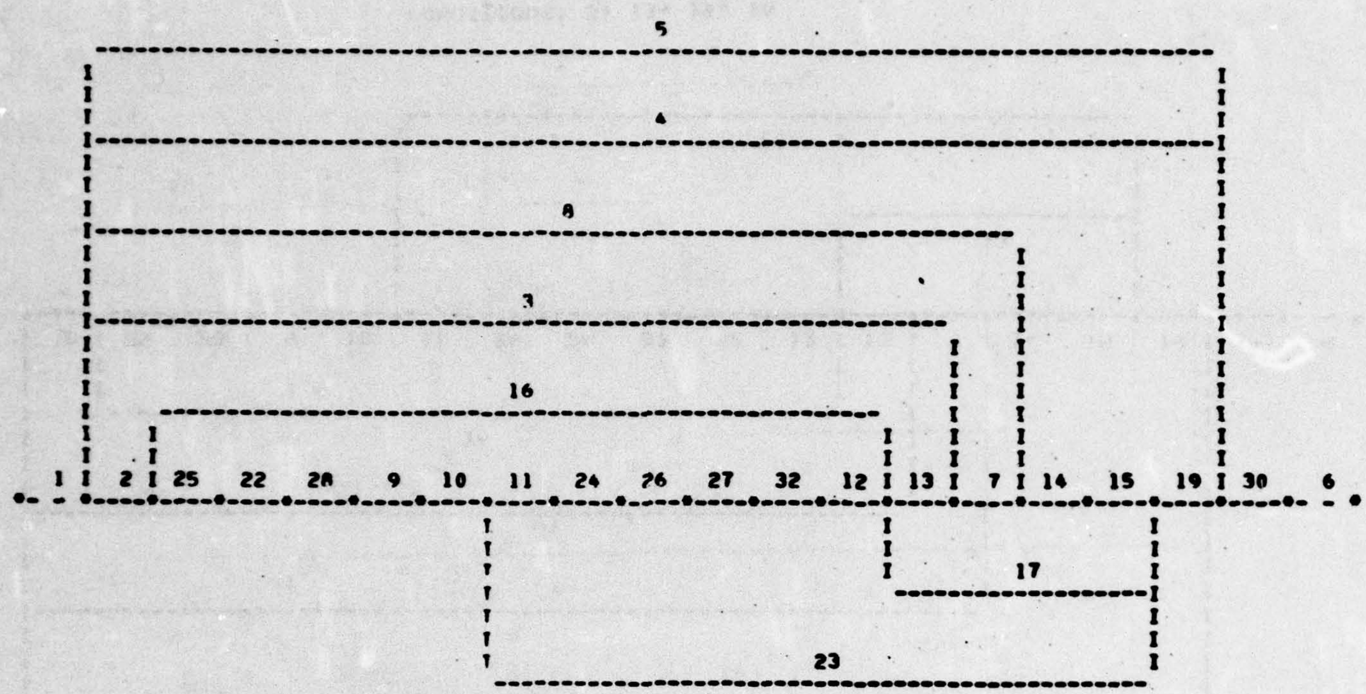


CONDITIONS: 3, 12, 15, 16
AE, ACCELERATED
AMOUNT
600000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



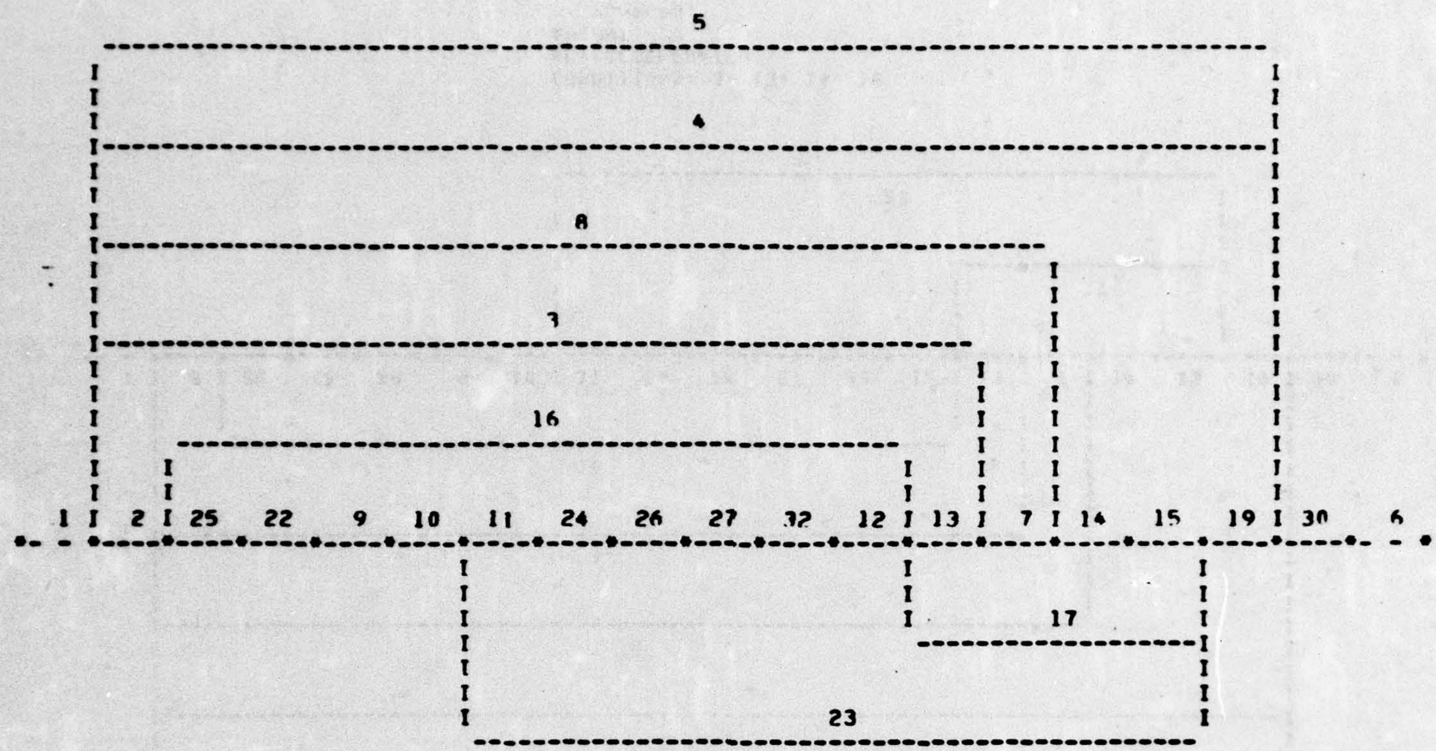
CONDITIONS: 3, 13, 14, 15
AE, ACCELERATED
AMOUNT
2000000.

AE, DELAY IN NOTICE TO PROCEED

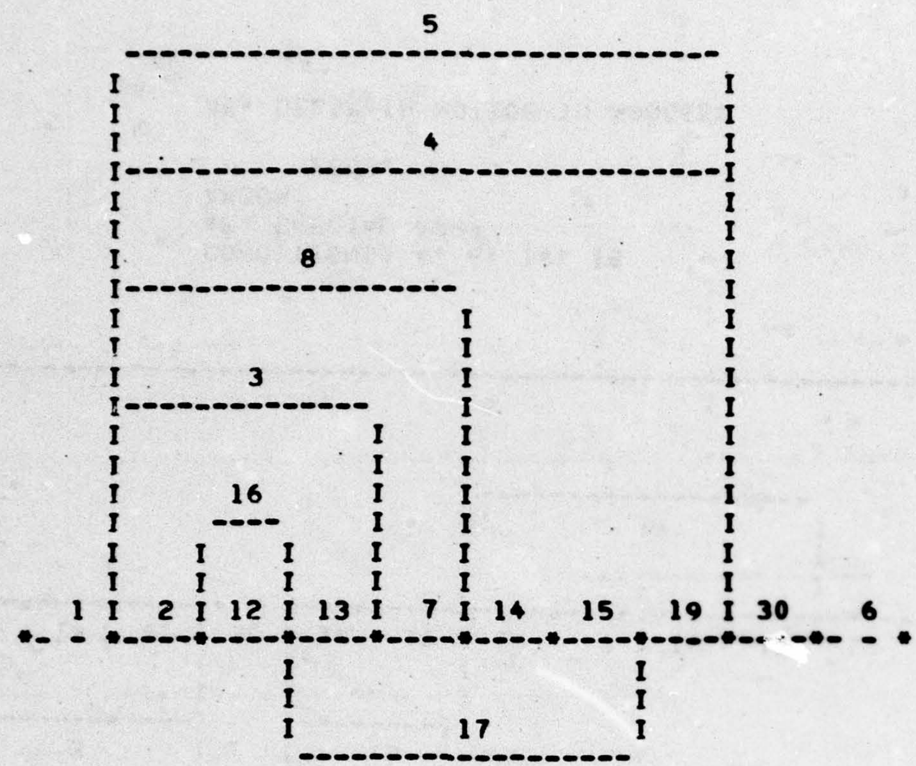


CONDITIONS: 3, 13, 14, 16
AE, ACCELERATED
AMOUNT
   2000000.

AE, DELAY IN DES DIRECTIVE

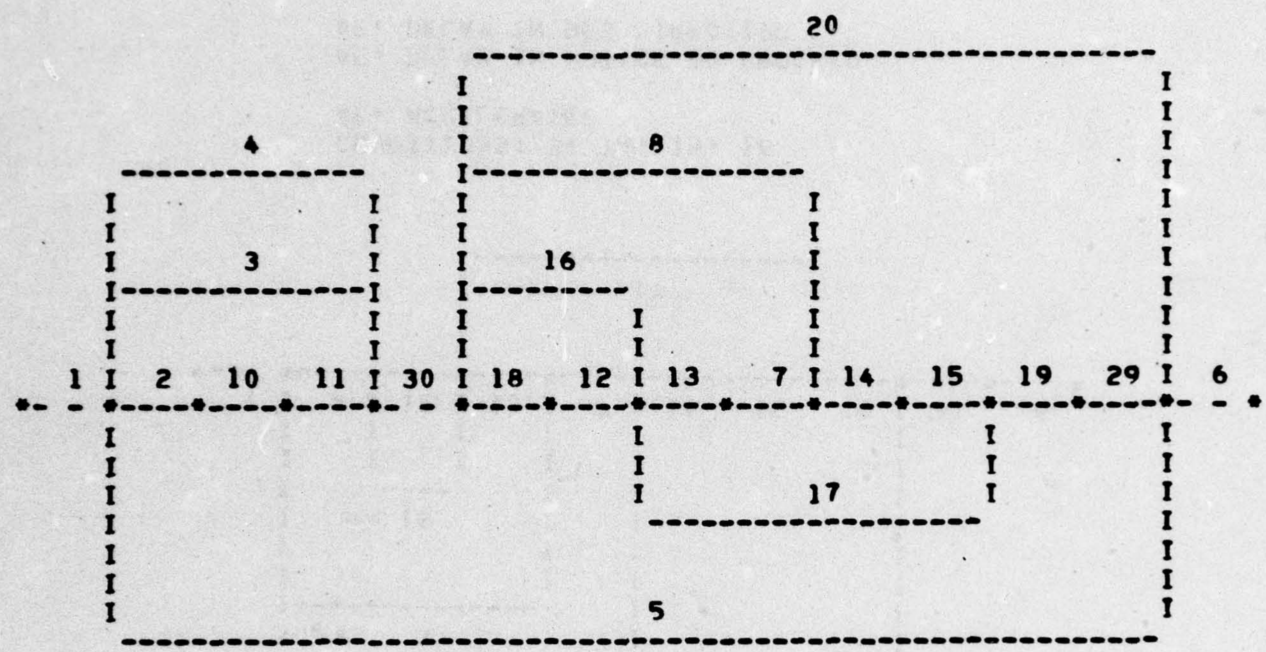


CONDITIONS: 3, 13, 15, 16
AE, ACCELERATED
AMOUNT
2000000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



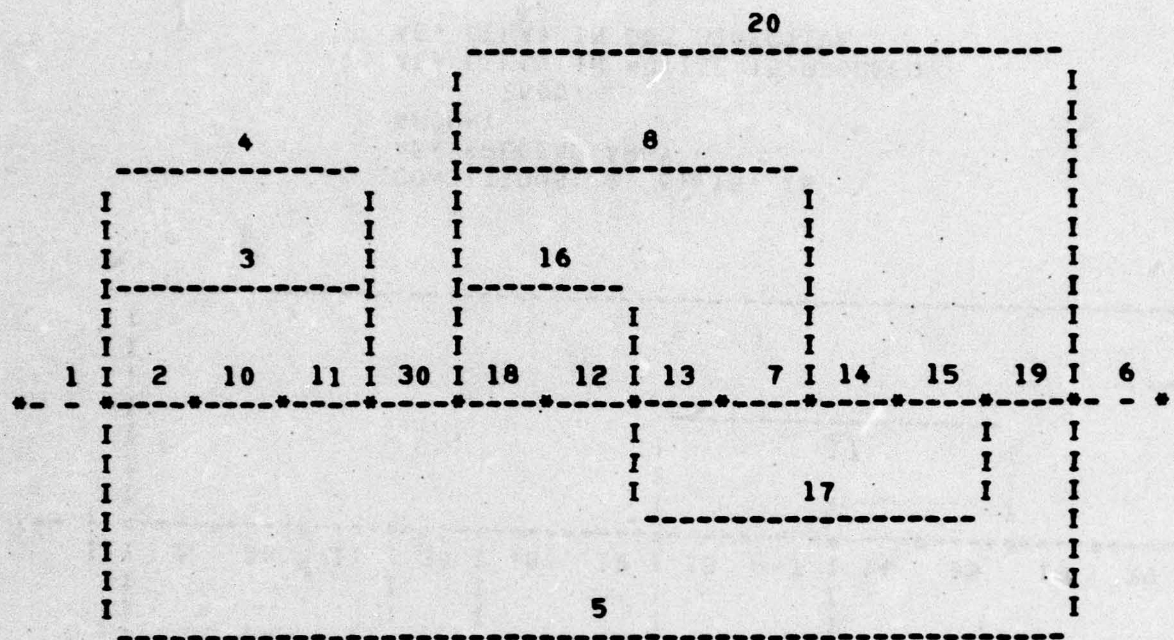
CONDITIONS: 3, 14, 15, 16
AE, ACCELERATED

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



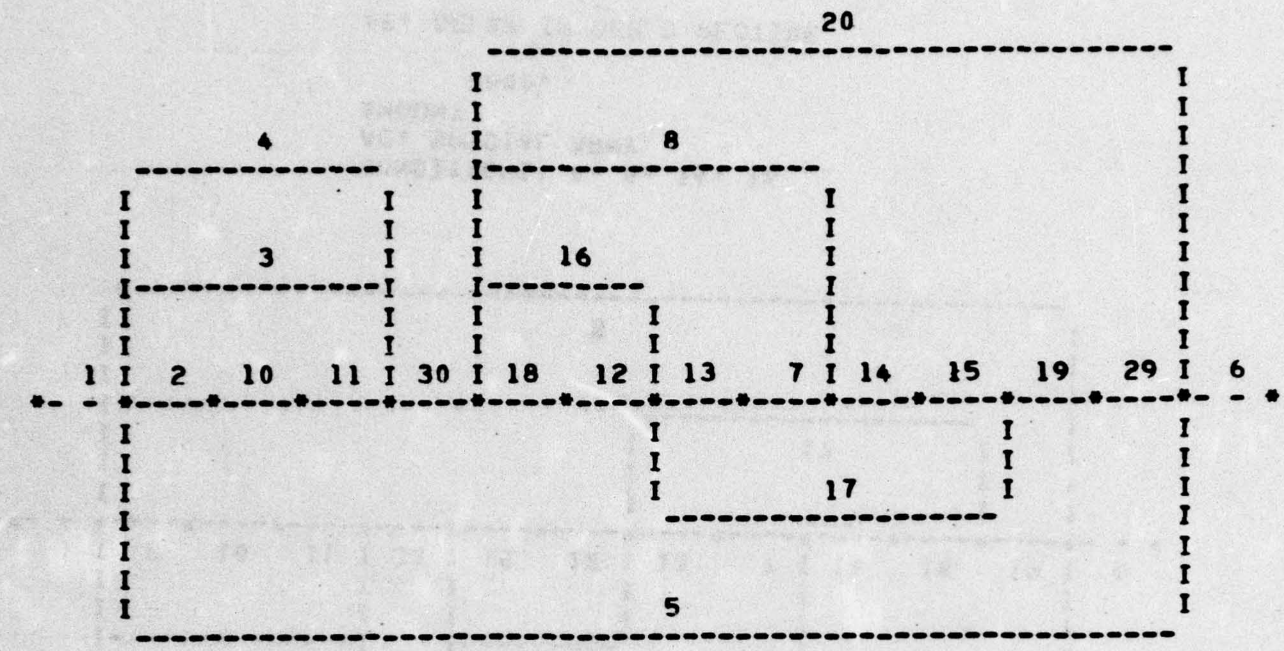
CONDITIONS: 4, 6, 14, 15
AE, SPECIAL ARMY
AMOUNT
2600.

AE, DELAY IN NOTICE TO PROCEED

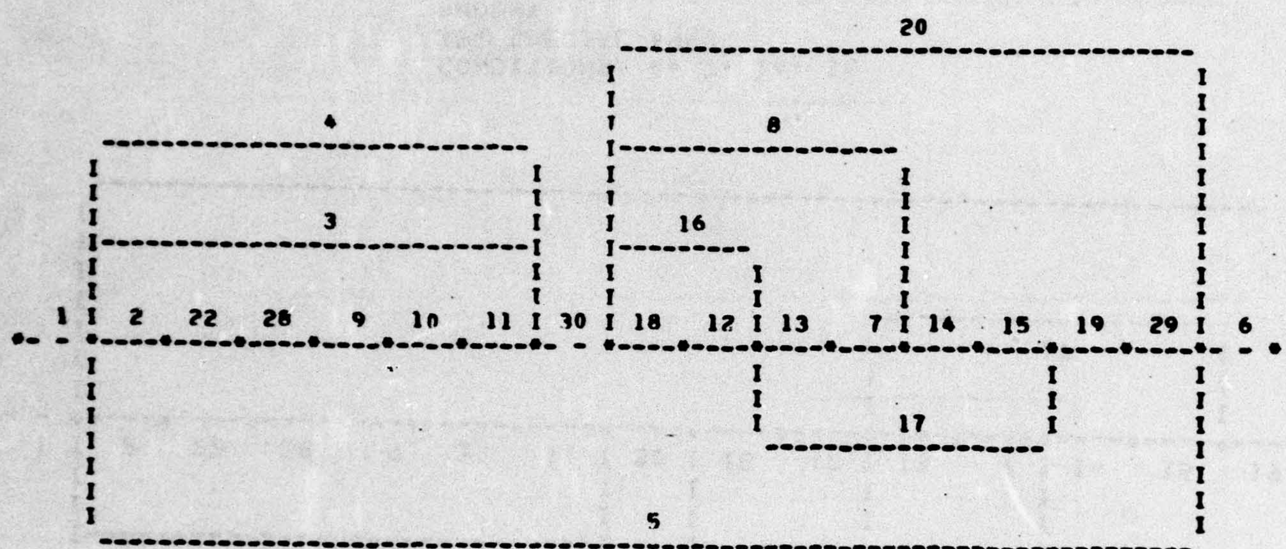


CONDITIONS: 4, 6, 14, 16
AE, SPECIAL ARMY
AMOUNT
2600.

AE, DELAY IN DES DIRECTIVE

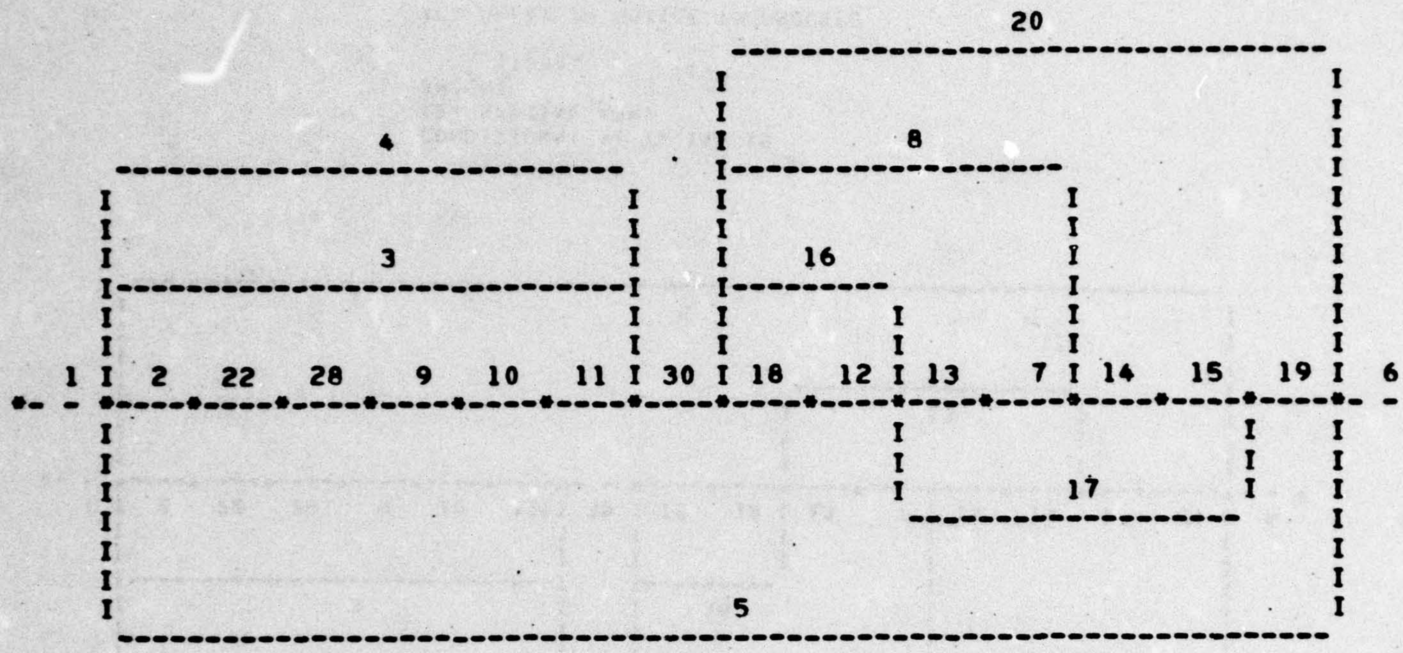


CONDITIONS: 4, 6, 15, 16
AE, SPECIAL ARMY
AMOUNT
2600.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



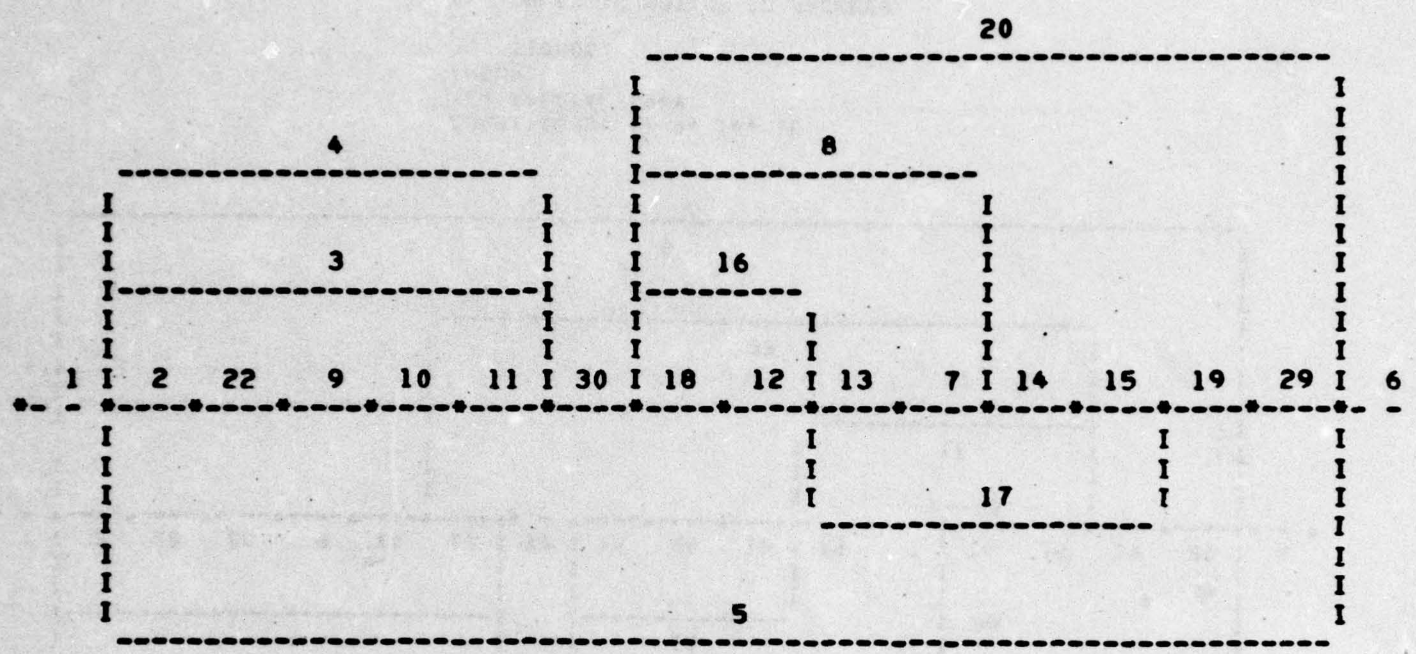
CONDITIONS: 4, 7, 14, 15
AE, SPECIAL ARMY
AMOUNT
11000.

AE, DELAY IN NOTICE TO PROCEED

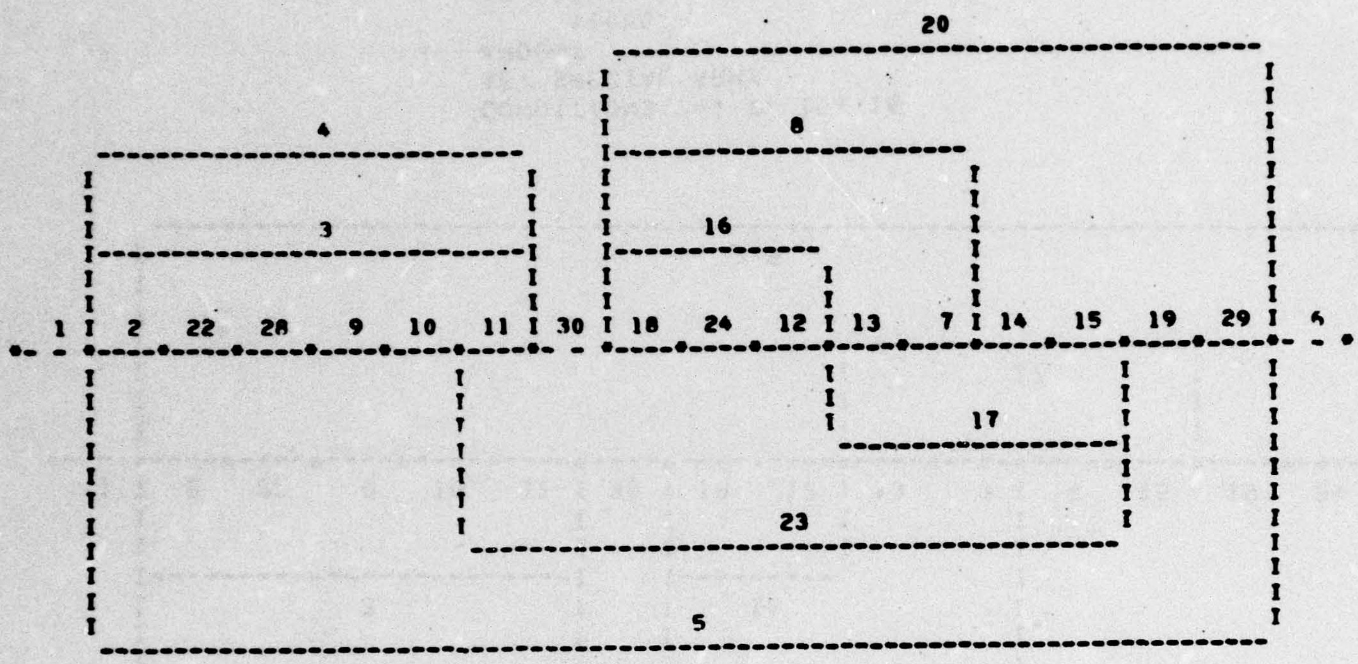


CONDITIONS: 4, 7, 14, 16
AE, SPECIAL ARMY
AMOUNT
11000.

AE, DELAY IN DES DIRECTIVE

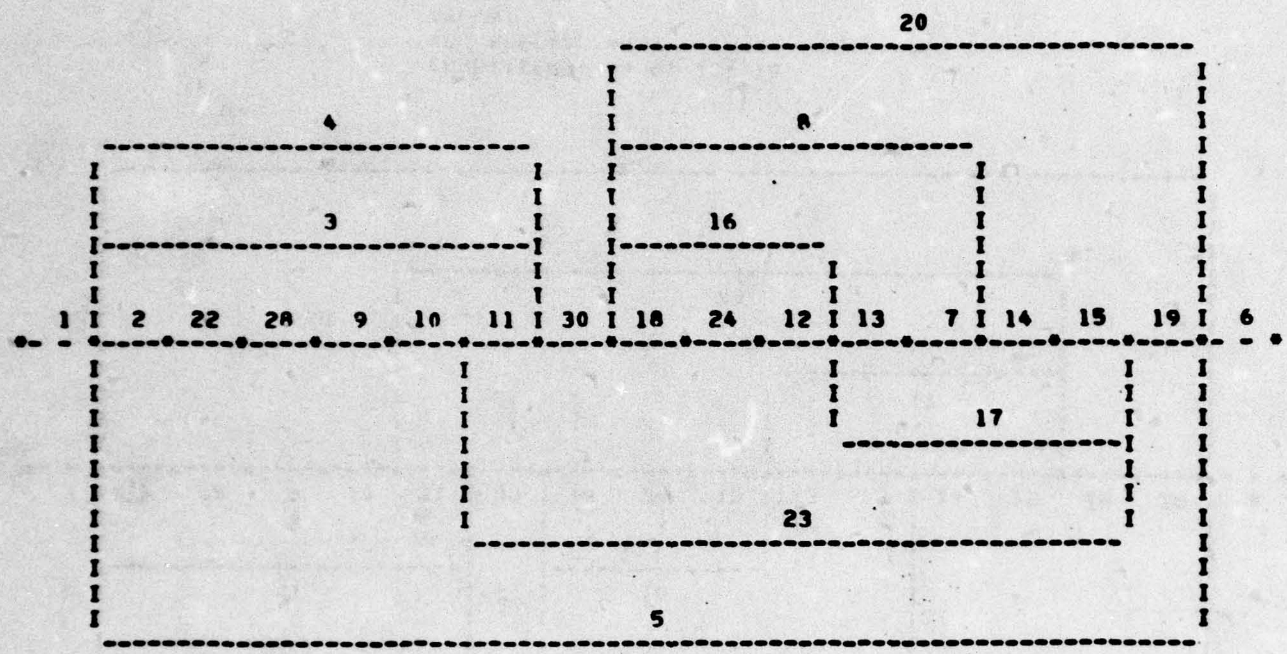


CONDITIONS: 4, 7, 15, 16
AE, SPECIAL ARMY
AMOUNT
11000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



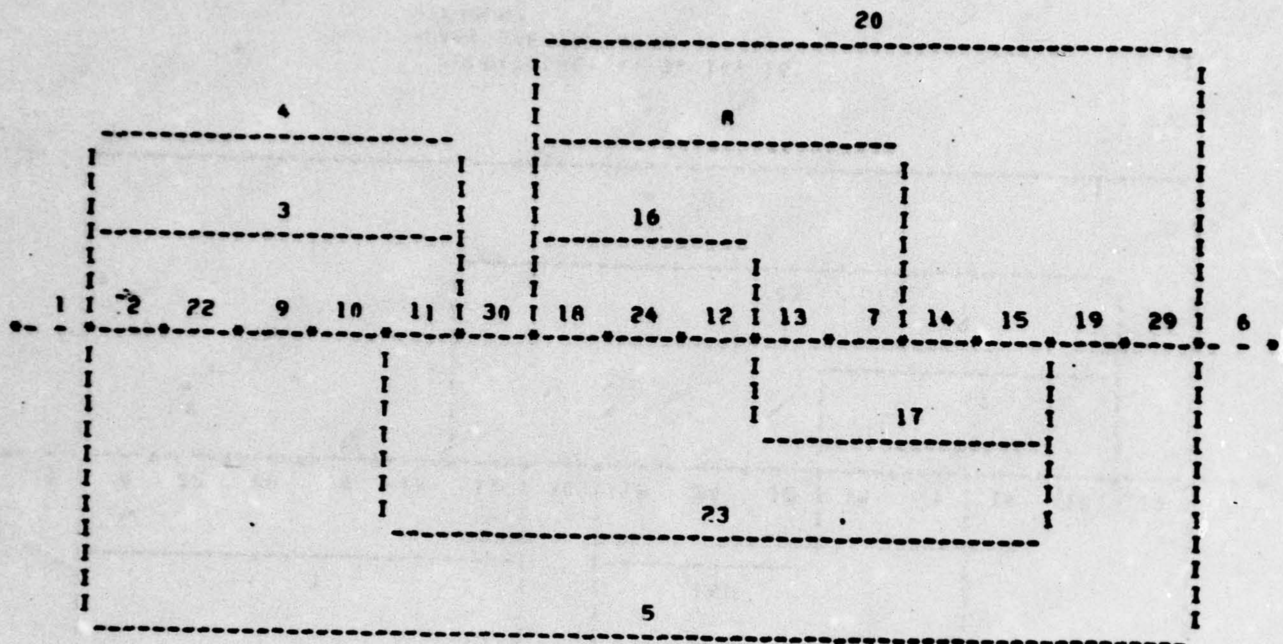
CONDITIONS: 4, 9, 14, 15
AE, SPECIAL ARMY
AMOUNT
110000.

AE, DELAY IN NOTICE TO PROCEED

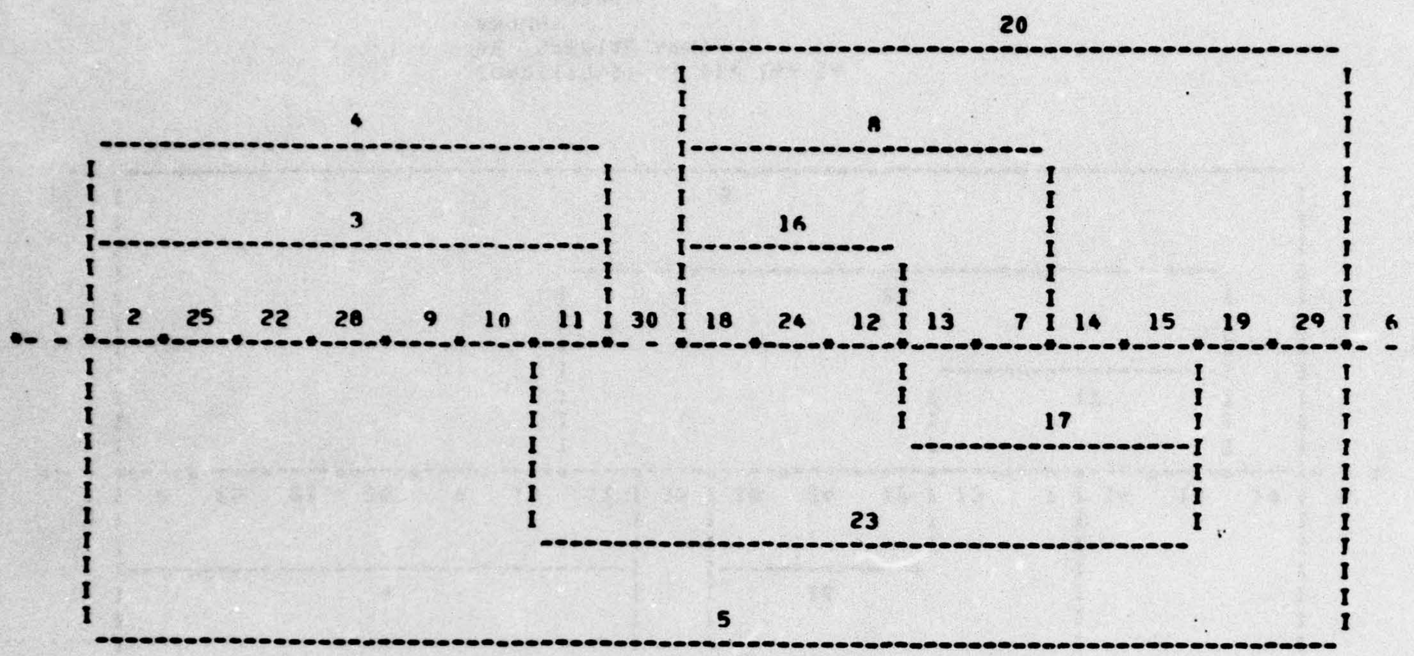


CONDITIONS: 4, 9, 14, 16
AE, SPECIAL ARMY
AMOUNT
110000.

AE, DELAY IN DES DIRECTIVE

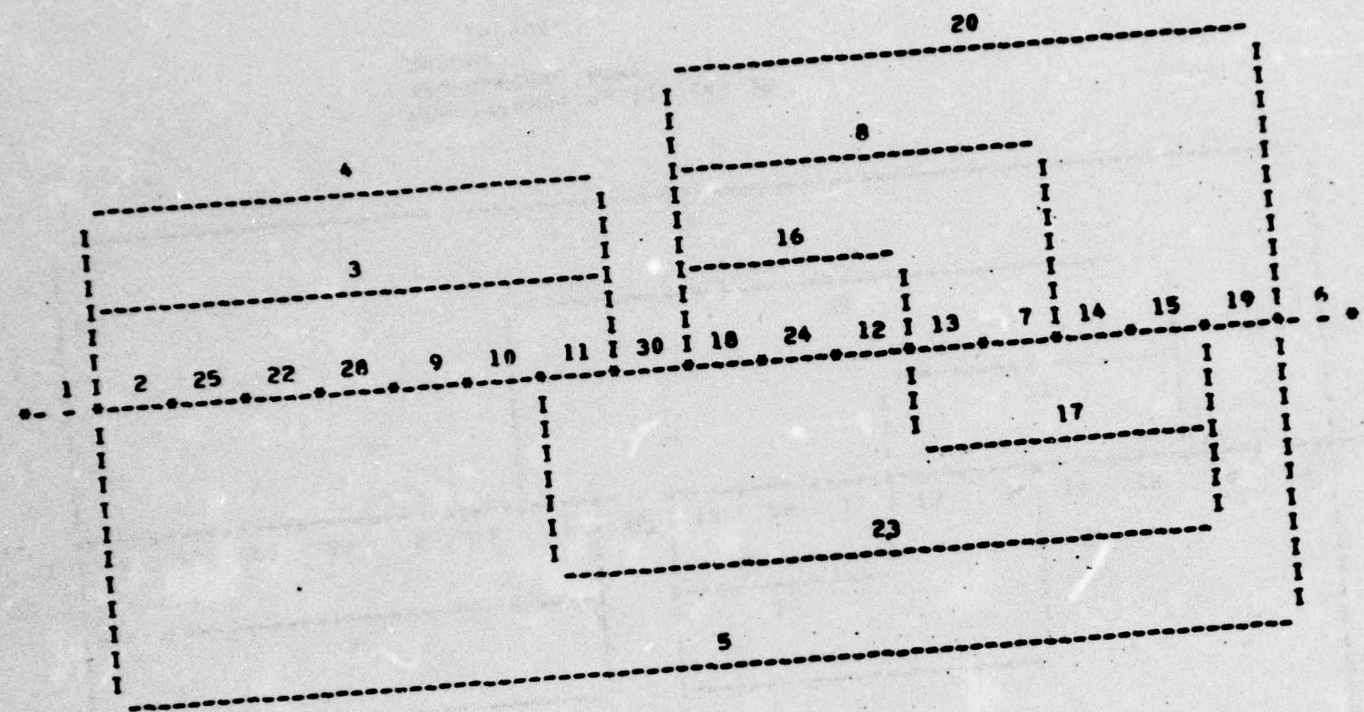


CONDITIONS: 4, 9, 15, 16
AF, SPECIAL ARMY
AMOUNT
    110000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



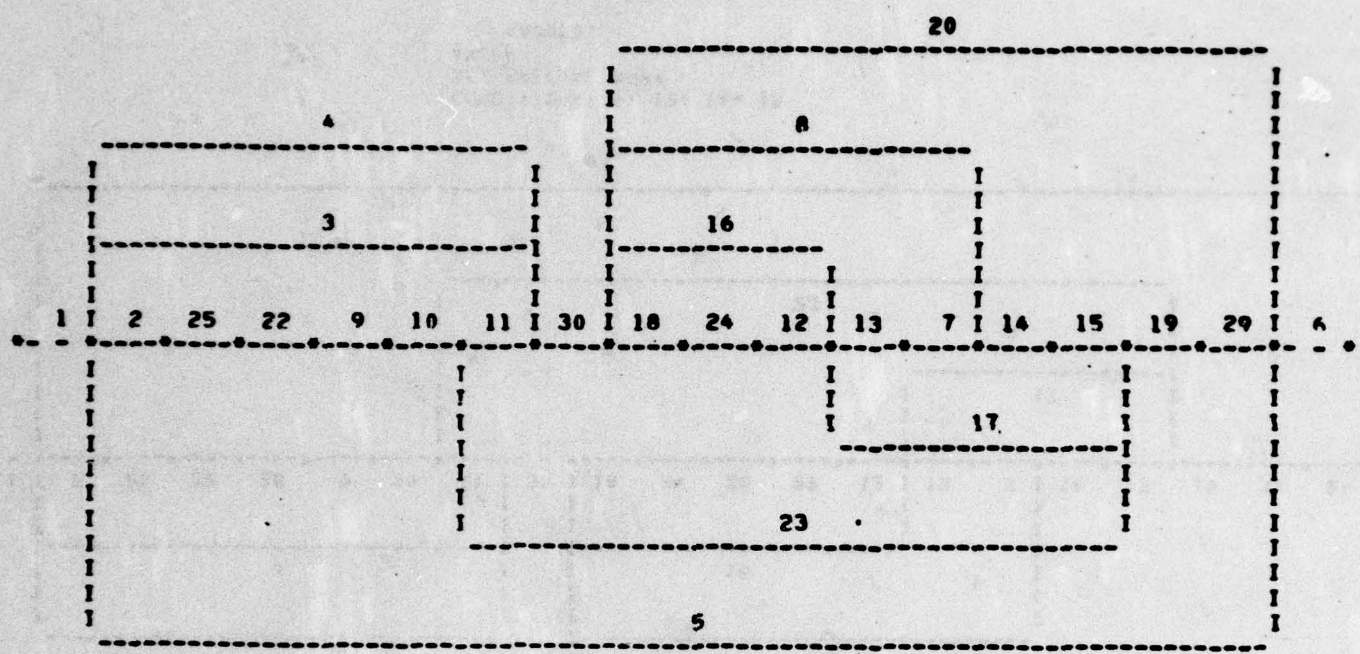
CONDITIONS: 4, 11, 14, 15
AE, SPECIAL ARMY
AMOUNT
160000.

AE, DELAY IN NOTICE TO PROCEED

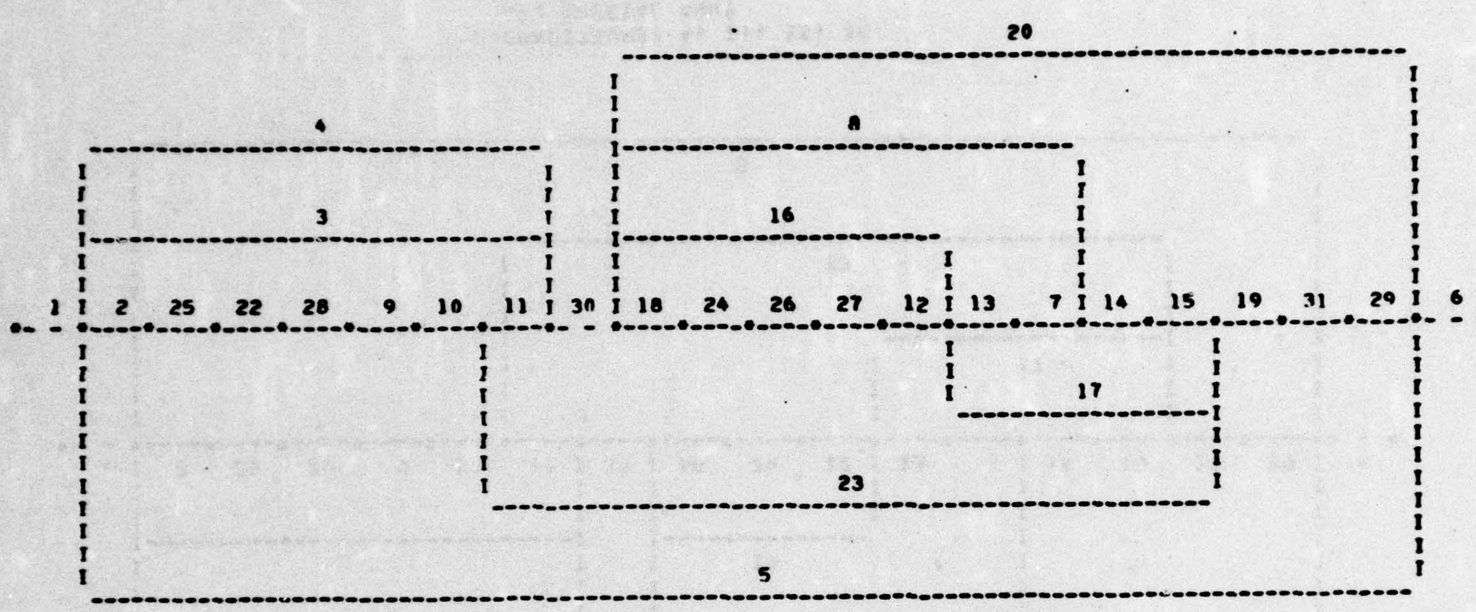


CONDITIONS: 4, 11, 14, 16
AE, SPECIAL ARMY
AMOUNT
160000.

AE, DELAY IN DES DIRECTIVE

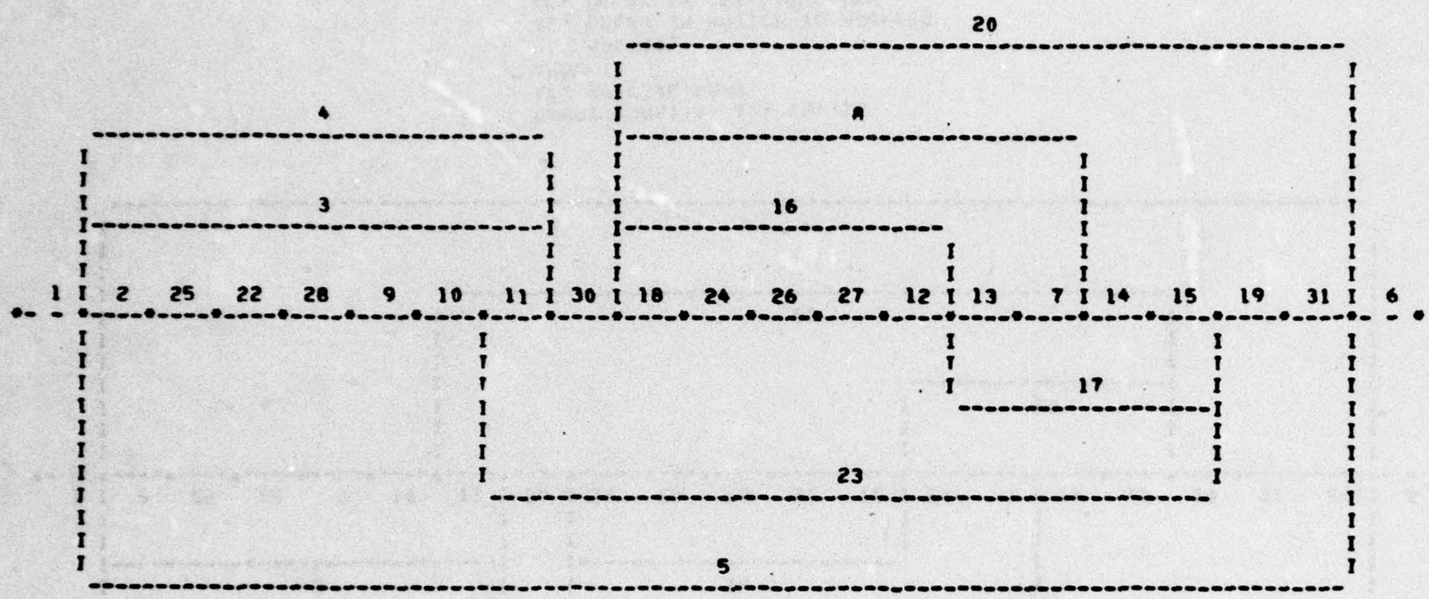


CONDITIONS: 4, 11, 15, 16
AE, SPECIAL ARMY
AMOUNT
160000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



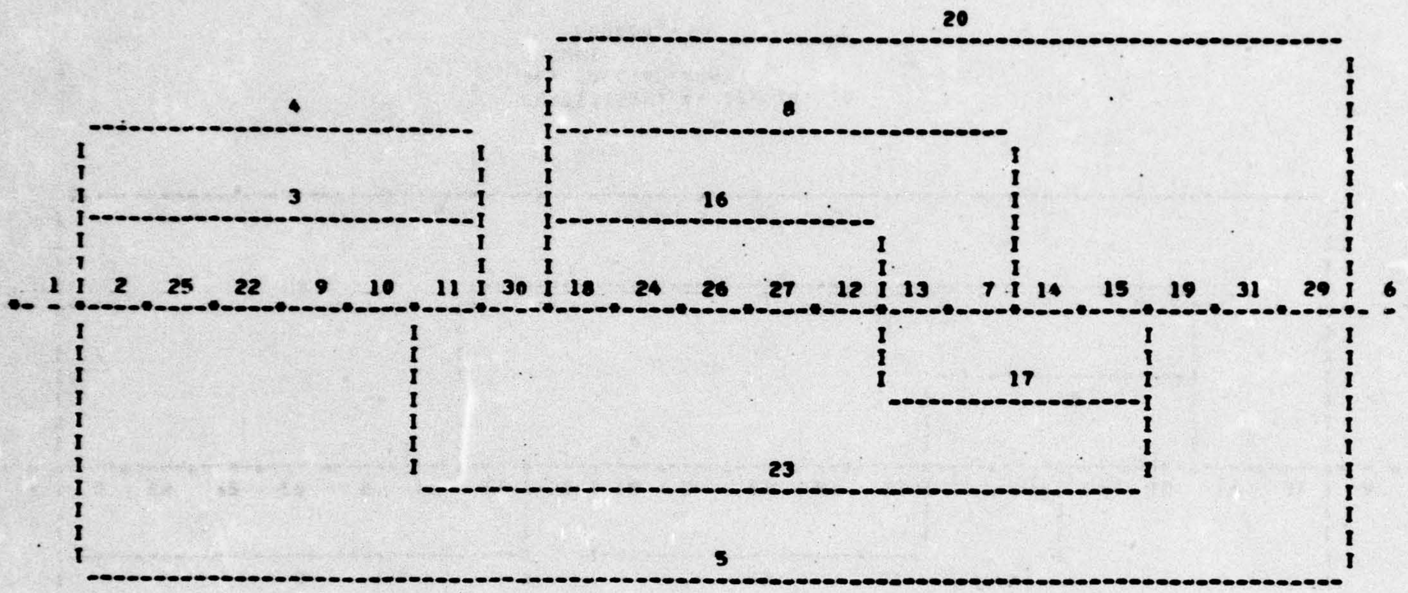
CONDITIONS: 4, 12, 14, 15
AE, SPECIAL ARMY
AMOUNT
    600000.

AE, DELAY IN NOTICE TO PROCEED

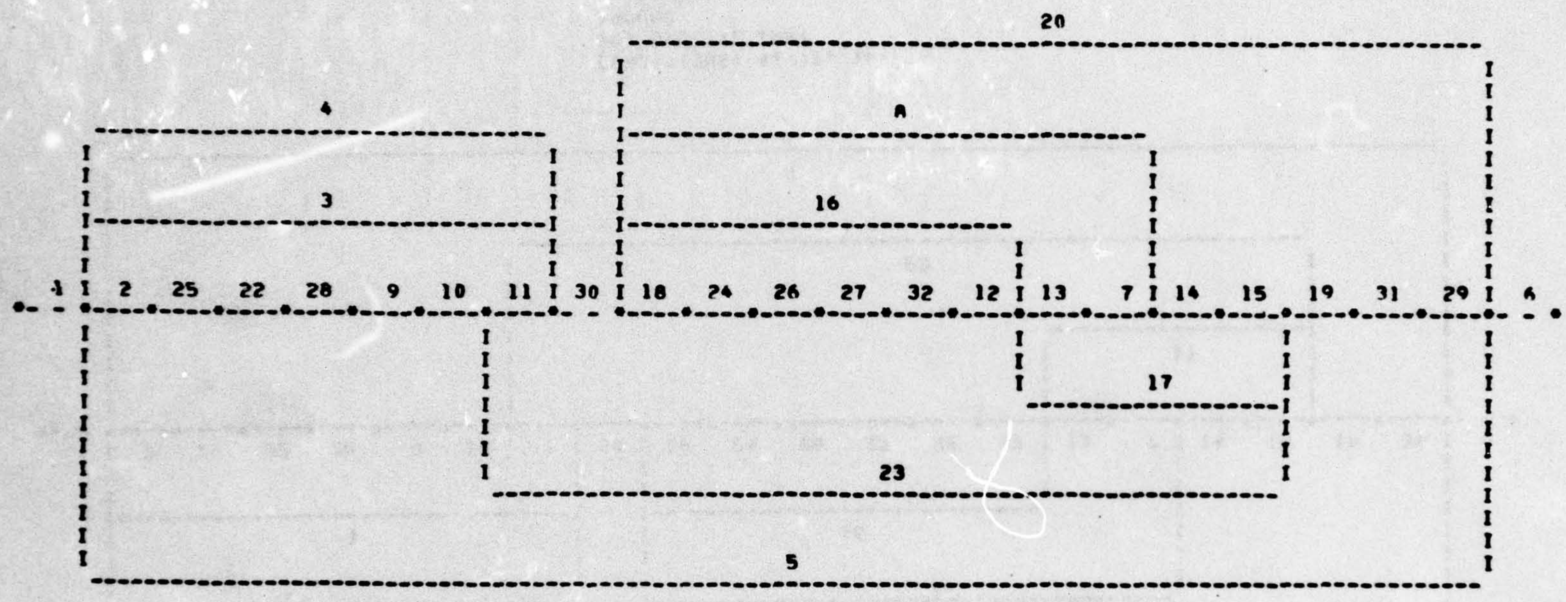


CONDITIONS: 4, 12, 14, 16
AE, SPECIAL ARMY
AMOUNT
600000.

AE. DELAY IN DES DIRECTIVE

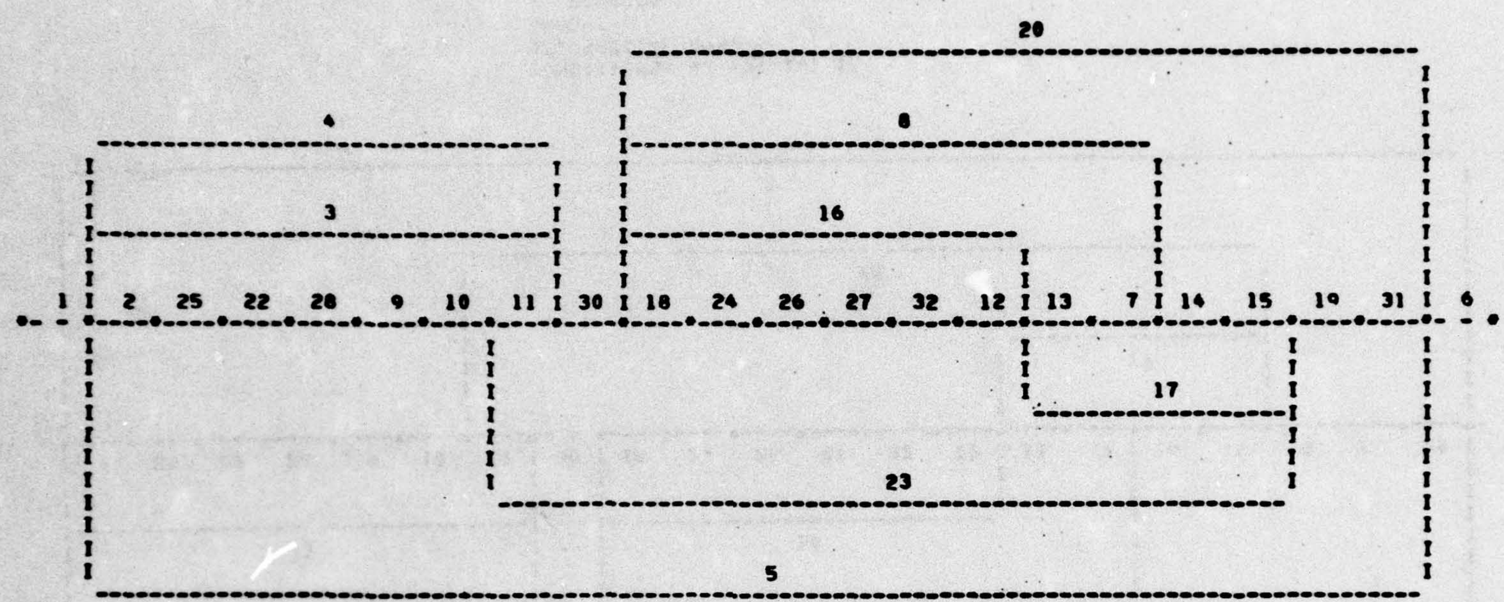


CONDITIONS: 4, 12, 15, 16
AE, SPECIAL ARMY
AMOUNT
    600000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



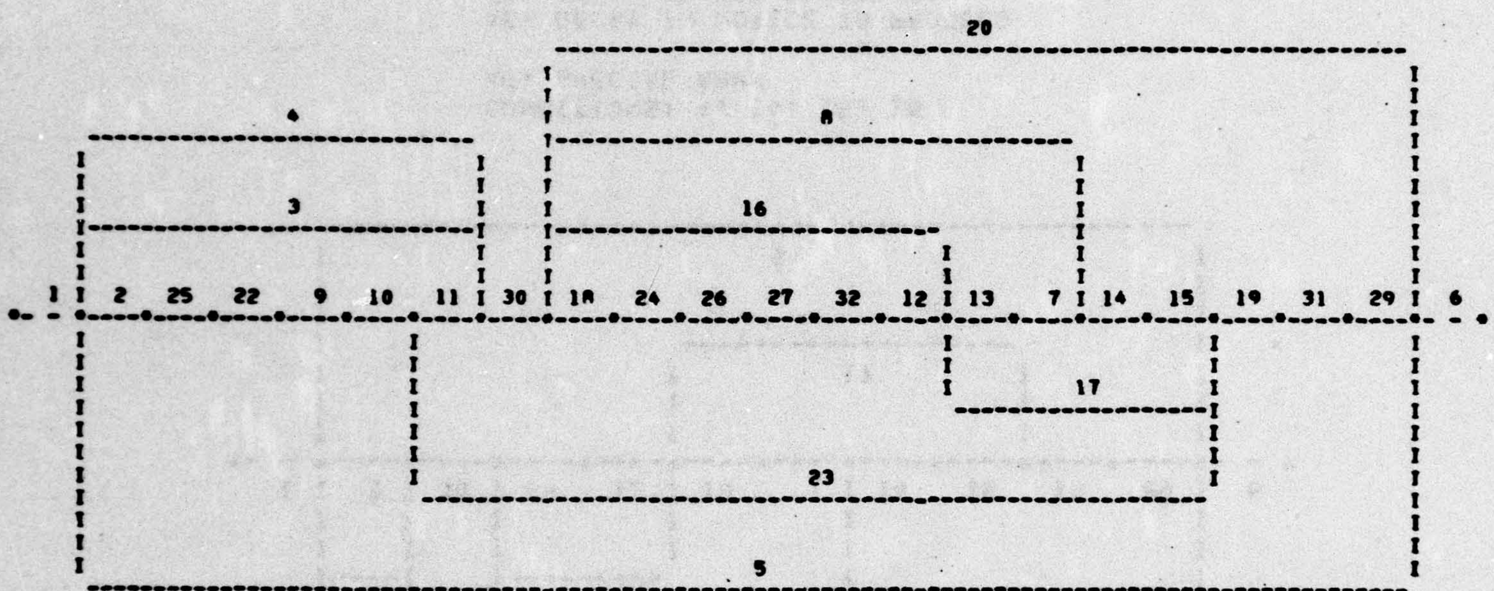
CONDITIONS: 4, 13, 14, 15
AE, SPECIAL ARMY
AMOUNT
2000000.

AE, DELAY IN NOTICE TO PROCEED

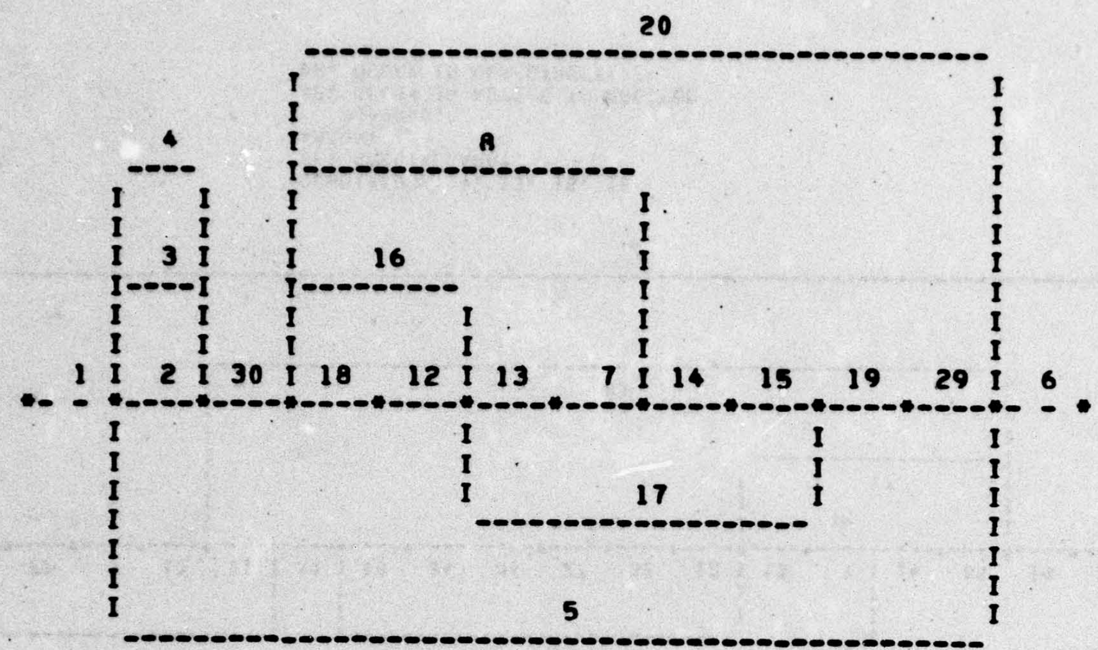


CONDITIONS: 4, 13, 14, 16
AE, SPECIAL ARMY
AMOUNT
2000000.

AE, DELAY IN DES DIRECTIVE

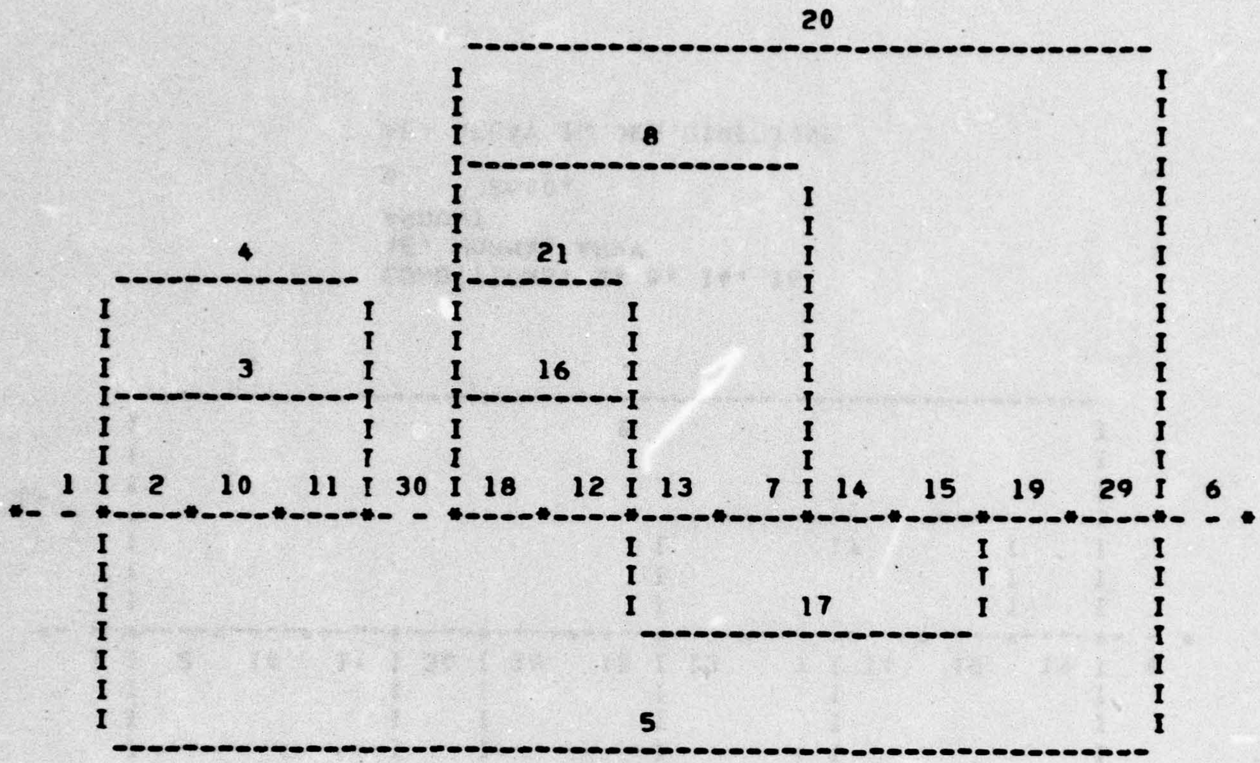


CONDITIONS: 4, 13, 15, 16
AE, SPECIAL ARMY
AMOUNT
   2000000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



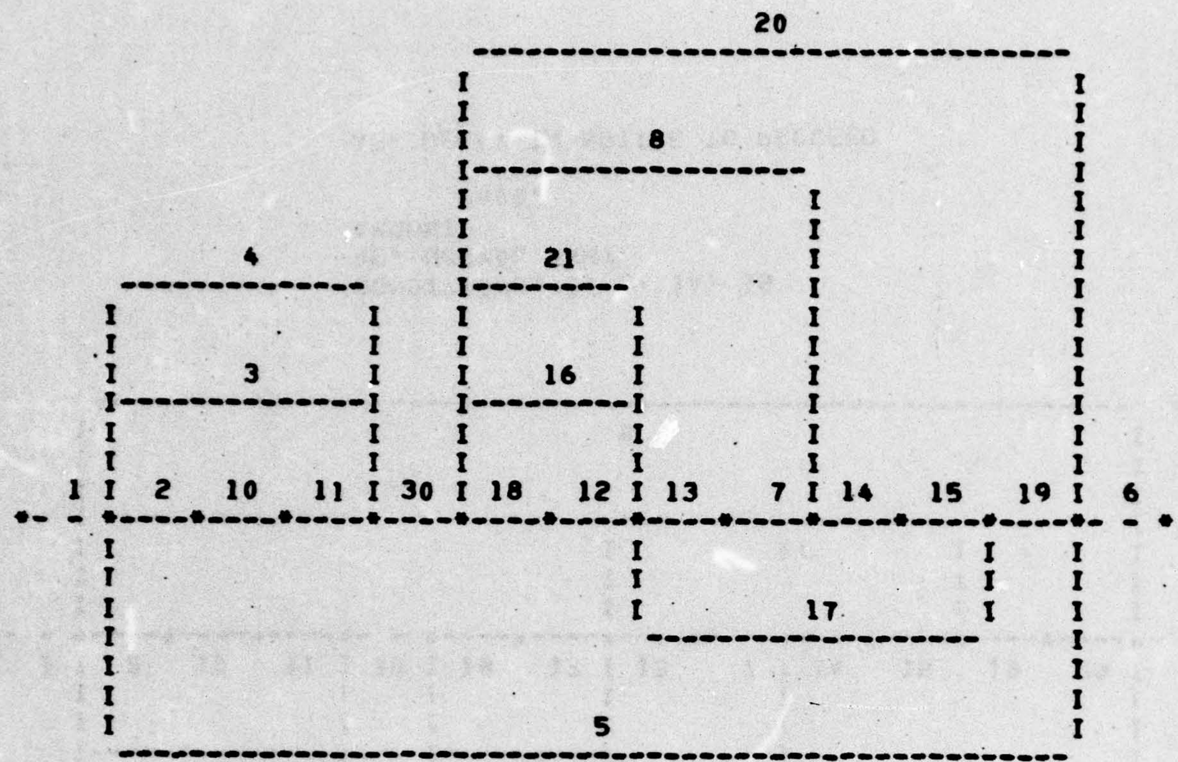
CONDITIONS: 4, 14, 15, 16
AE, SPECIAL ARMY

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



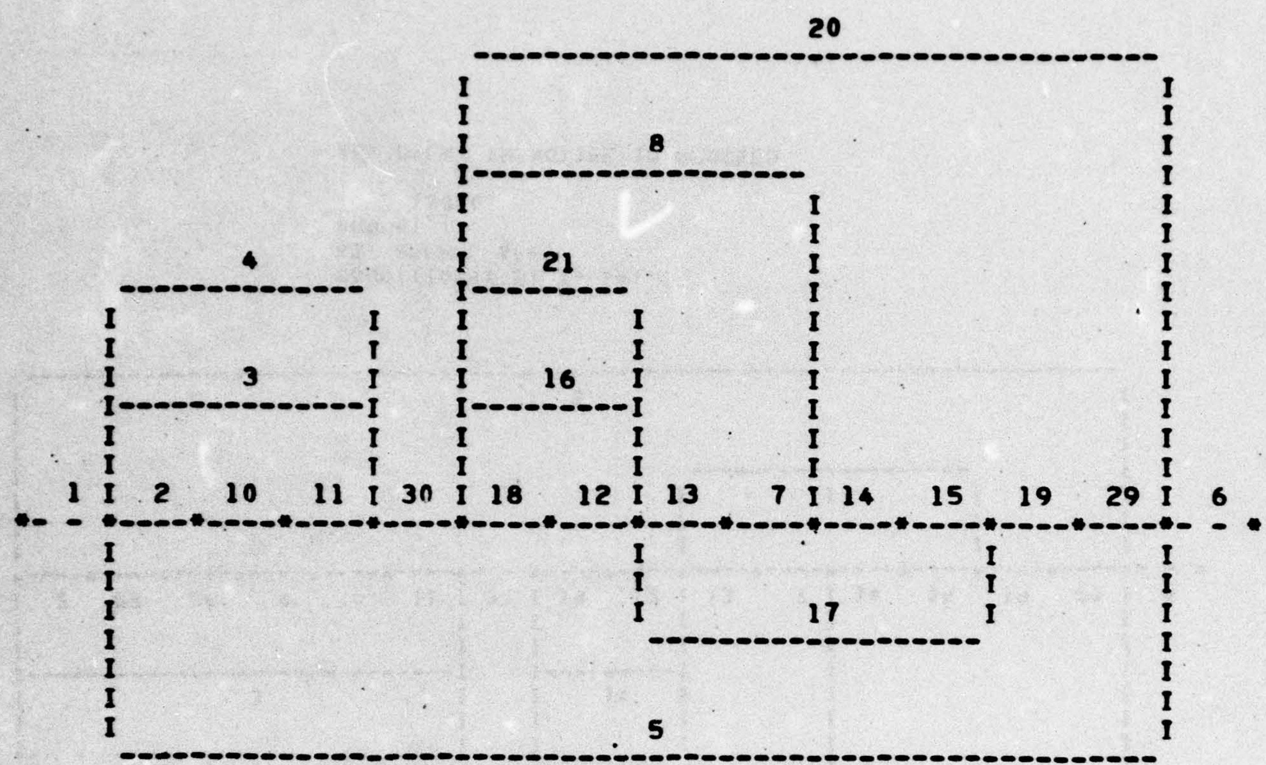
CONDITIONS: 5, 6, 14, 15
AE, NORMAL ARMY
AMOUNT
2600.

AE, DELAY IN NOTICE TO PROCEED

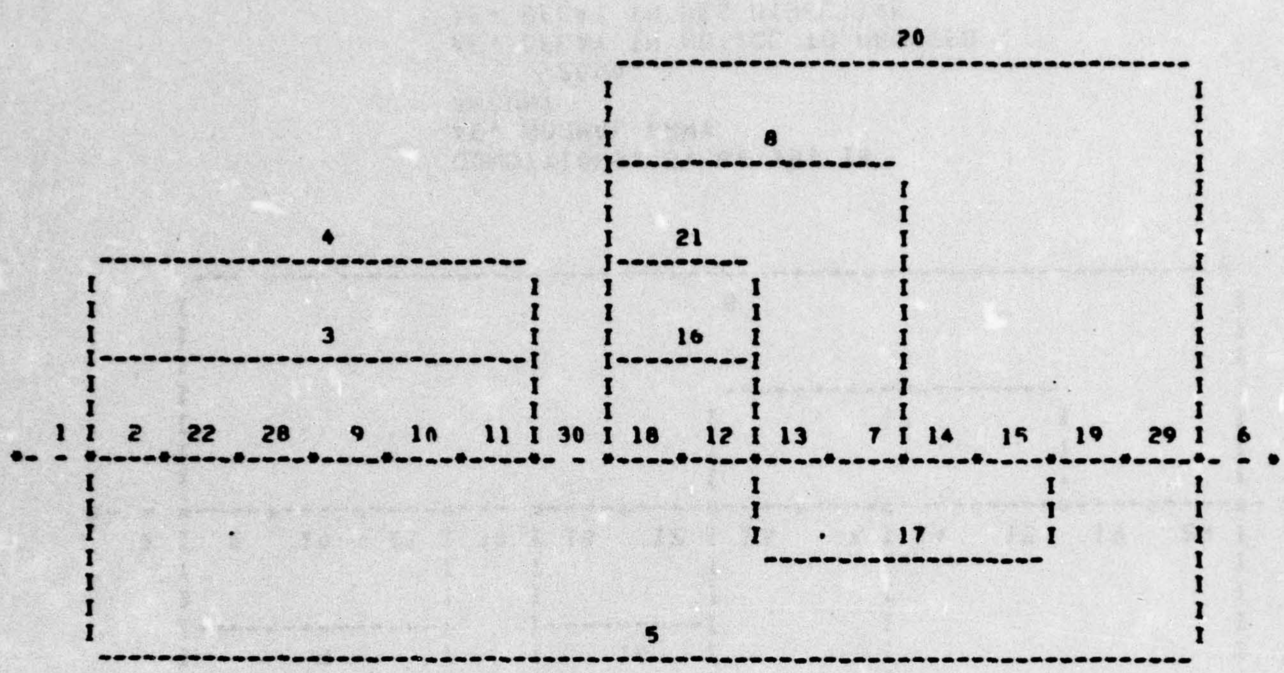


CONDITIONS: 5, 6, 14, 16
AE, NORMAL ARMY
AMOUNT
2600.

AE, DELAY IN DES DIRECTIVE

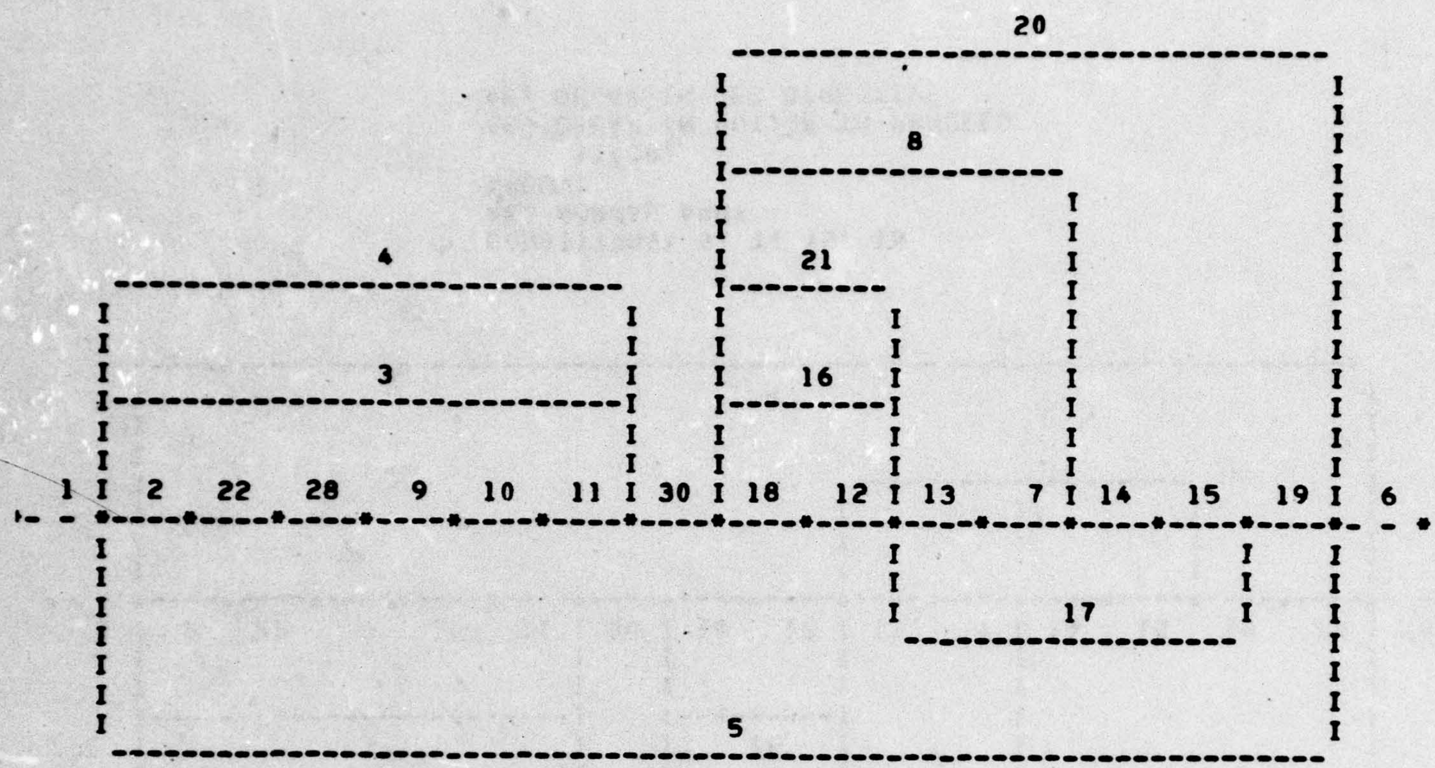


CONDITIONS: 5, 6, 15, 16
AE, NORMAL ARMY
AMOUNT
    2600.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



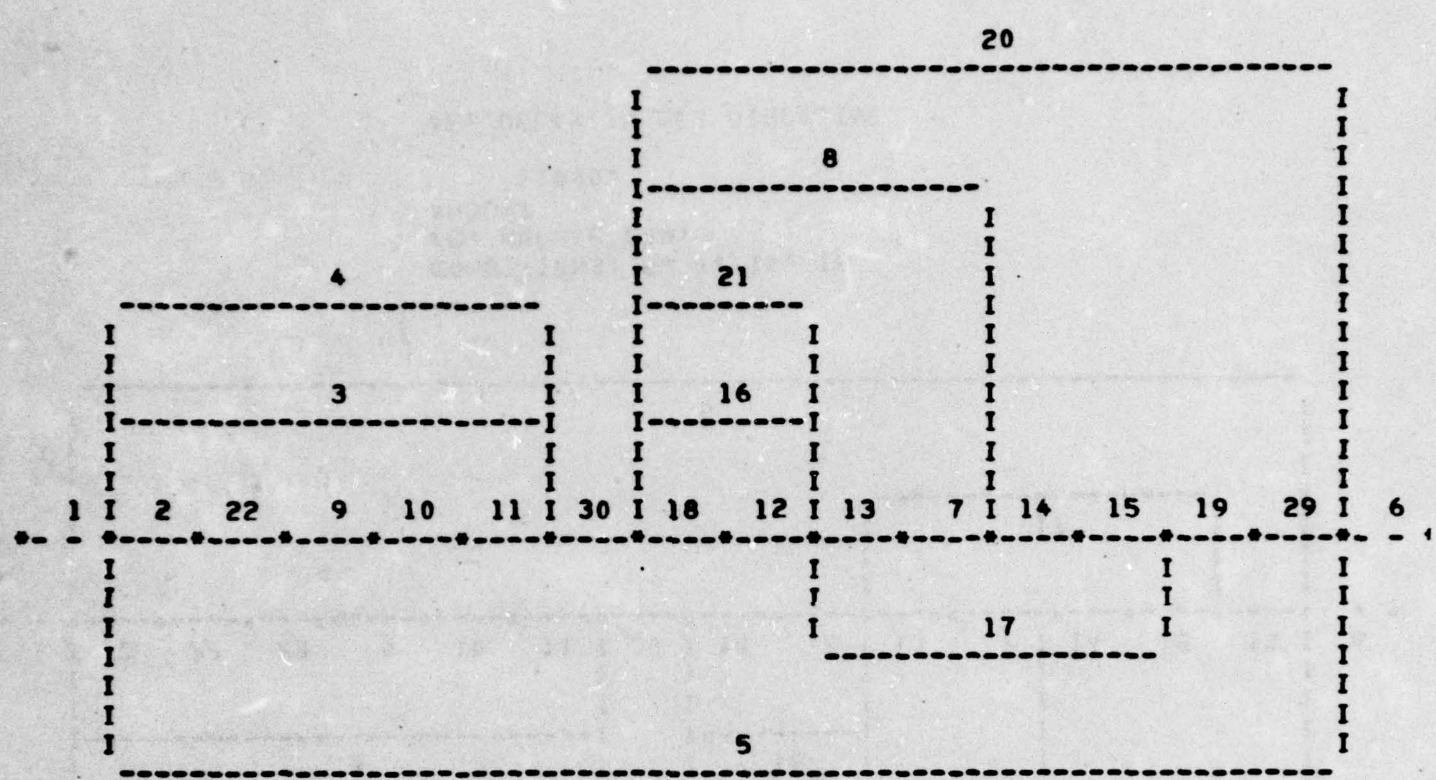
CONDITIONS: 5, 7, 14, 15
AE, NORMAL ARMY
AMOUNT
11000.

AE, DELAY IN NOTICE TO PROCEED

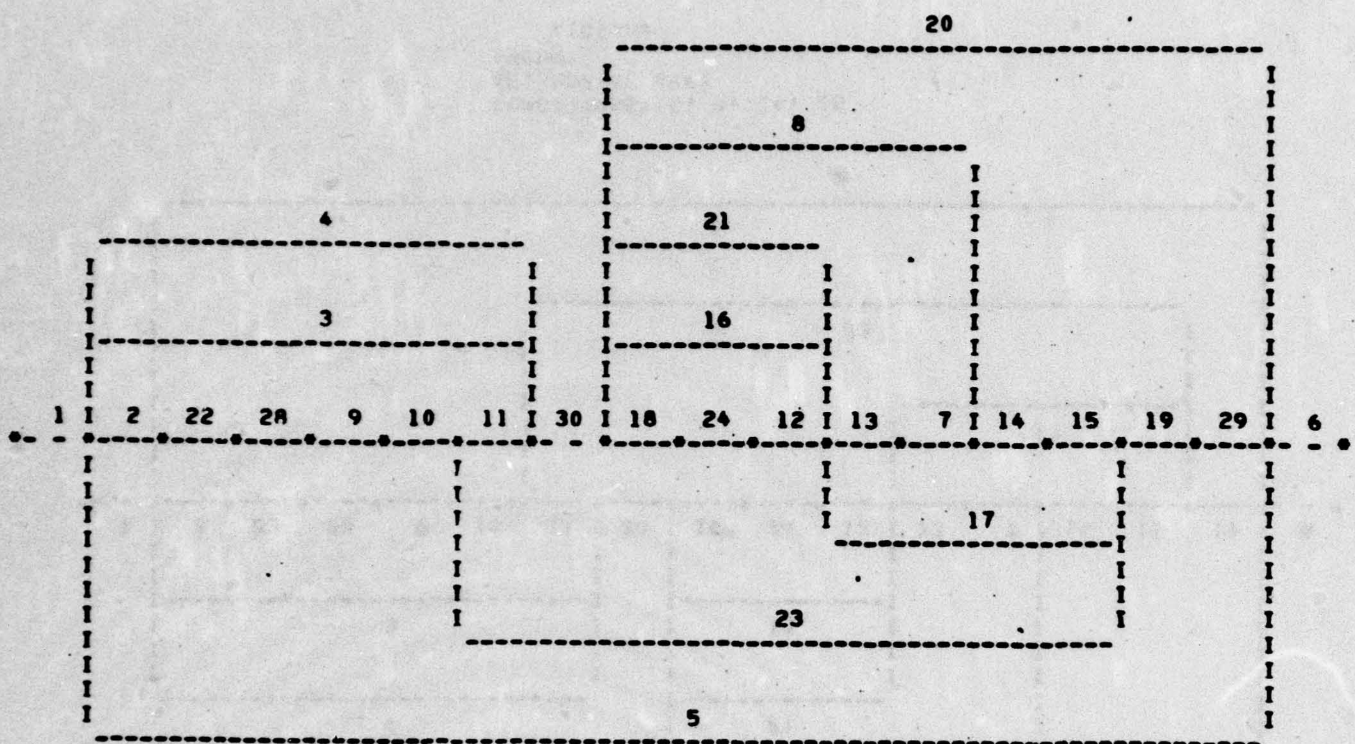


CONDITIONS: 5, 7, 14, 16
AE, NORMAL ARMY
AMOUNT
11000.

AE, DELAY IN DES DIRECTIVE

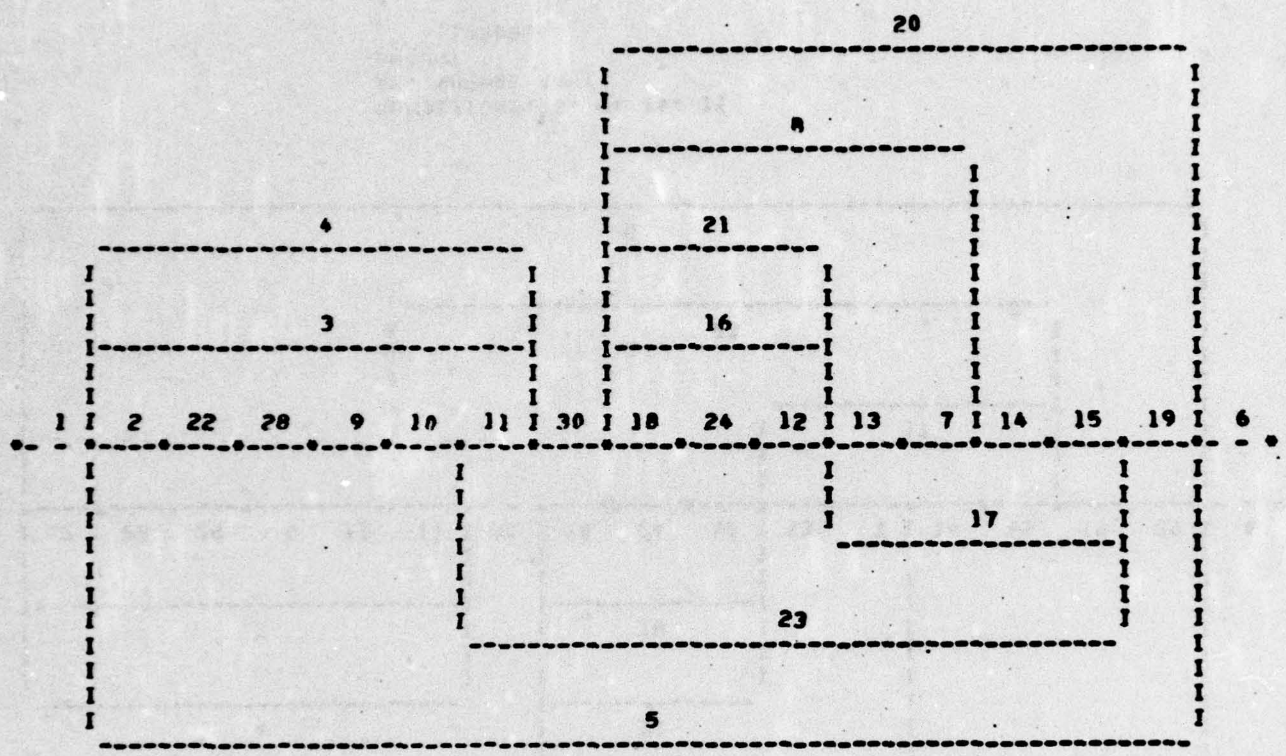


CONDITIONS: 5, 7, 15, 16
AE, NORMAL ARMY
AMOUNT
    11000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



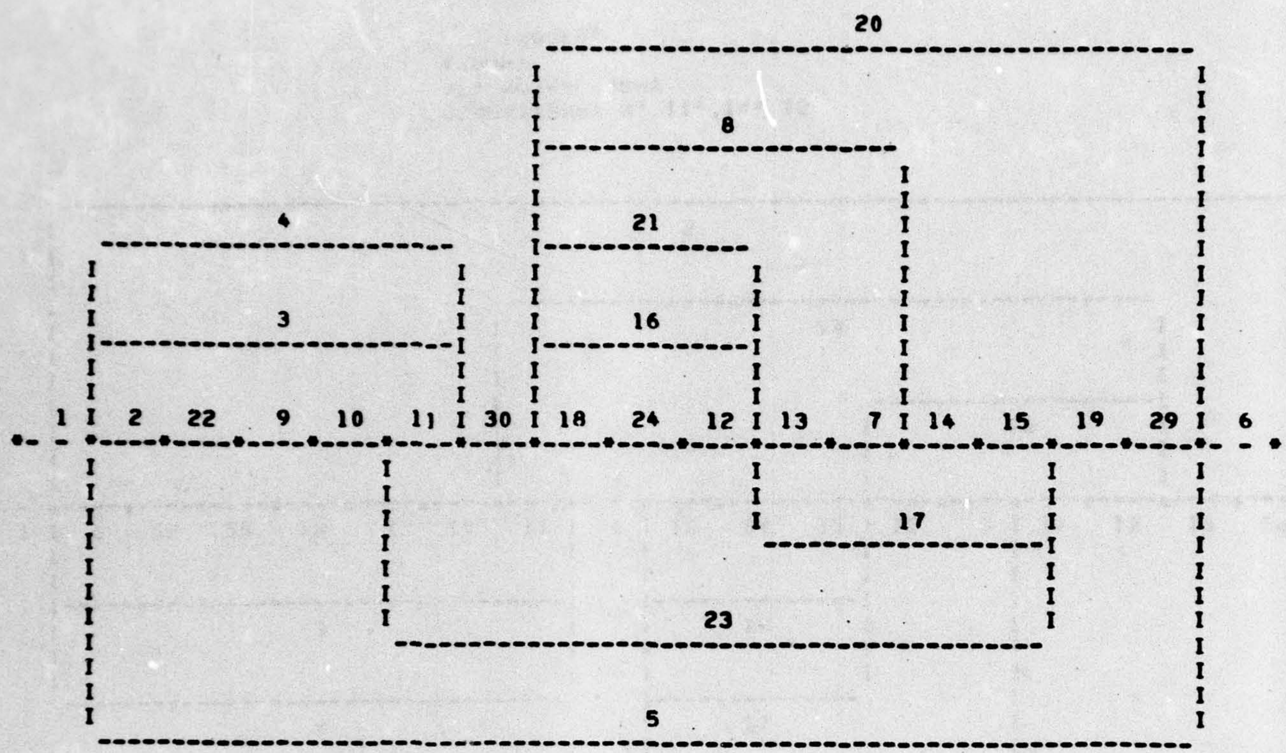
CONDITIONS: 5, 9, 14, 15
AE, NORMAL ARMY
AMOUNT
110000.

AE, DELAY IN NOTICE TO PROCEED

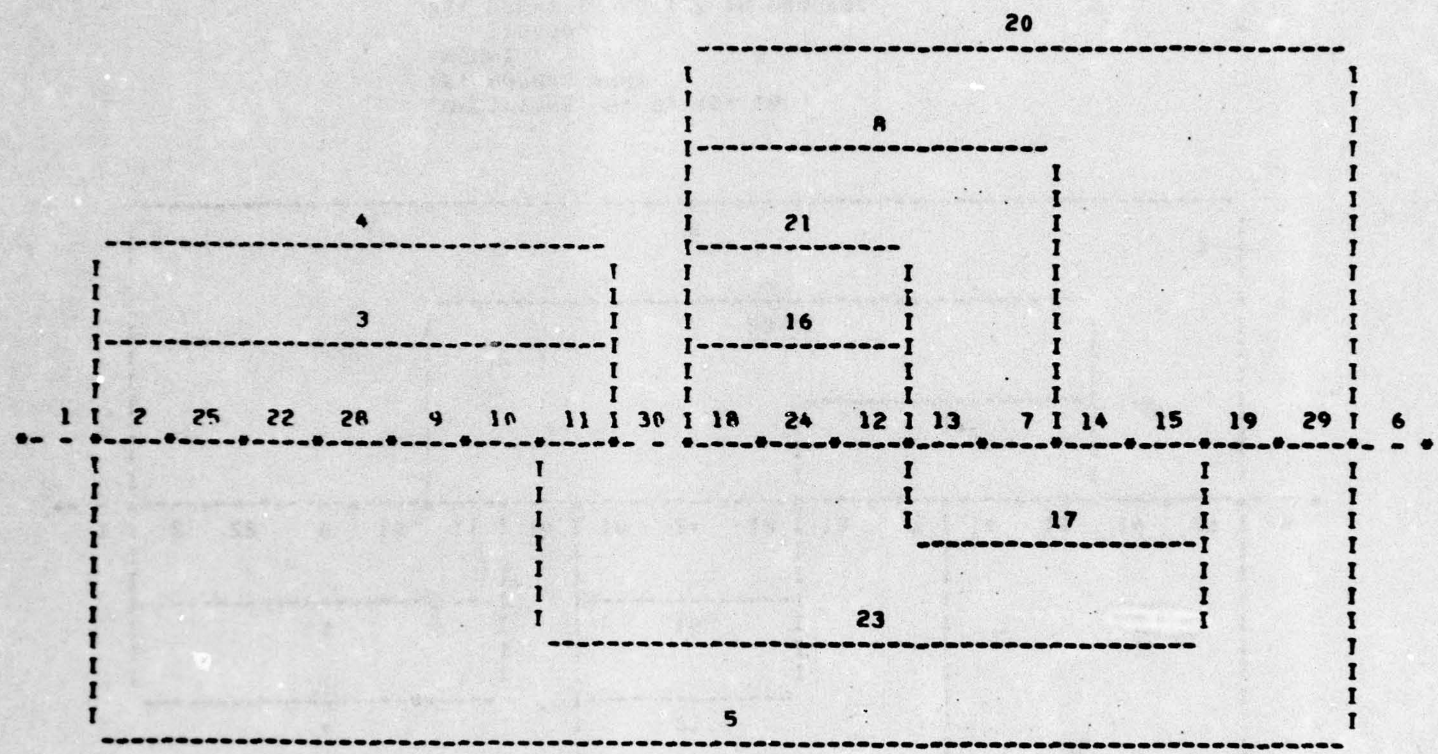


CONDITIONS: 5, 9, 14, 16
AE, NORMAL ARMY
AMOUNT
110000.

AE, DELAY IN DES DIRECTIVE

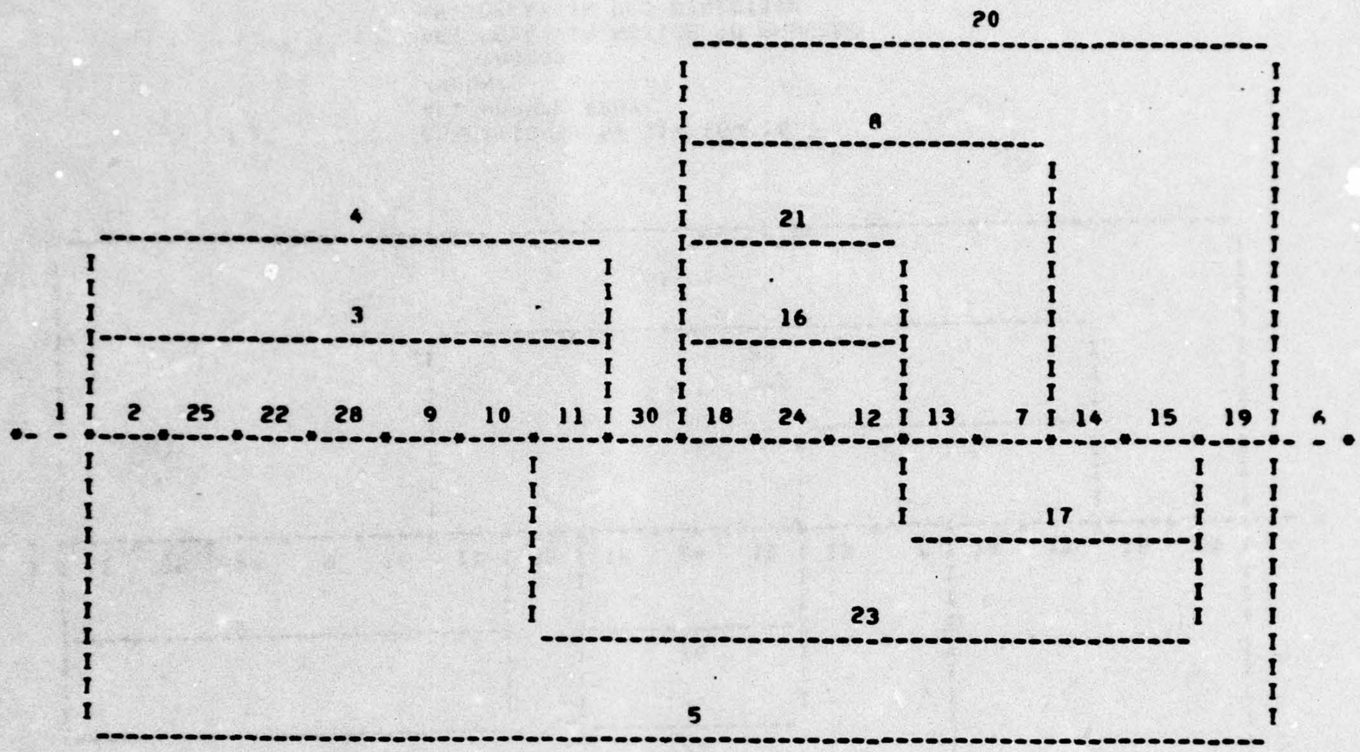


CONDITIONS: 5, 9, 15, 16
AE, NORMAL ARMY
AMOUNT
110000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



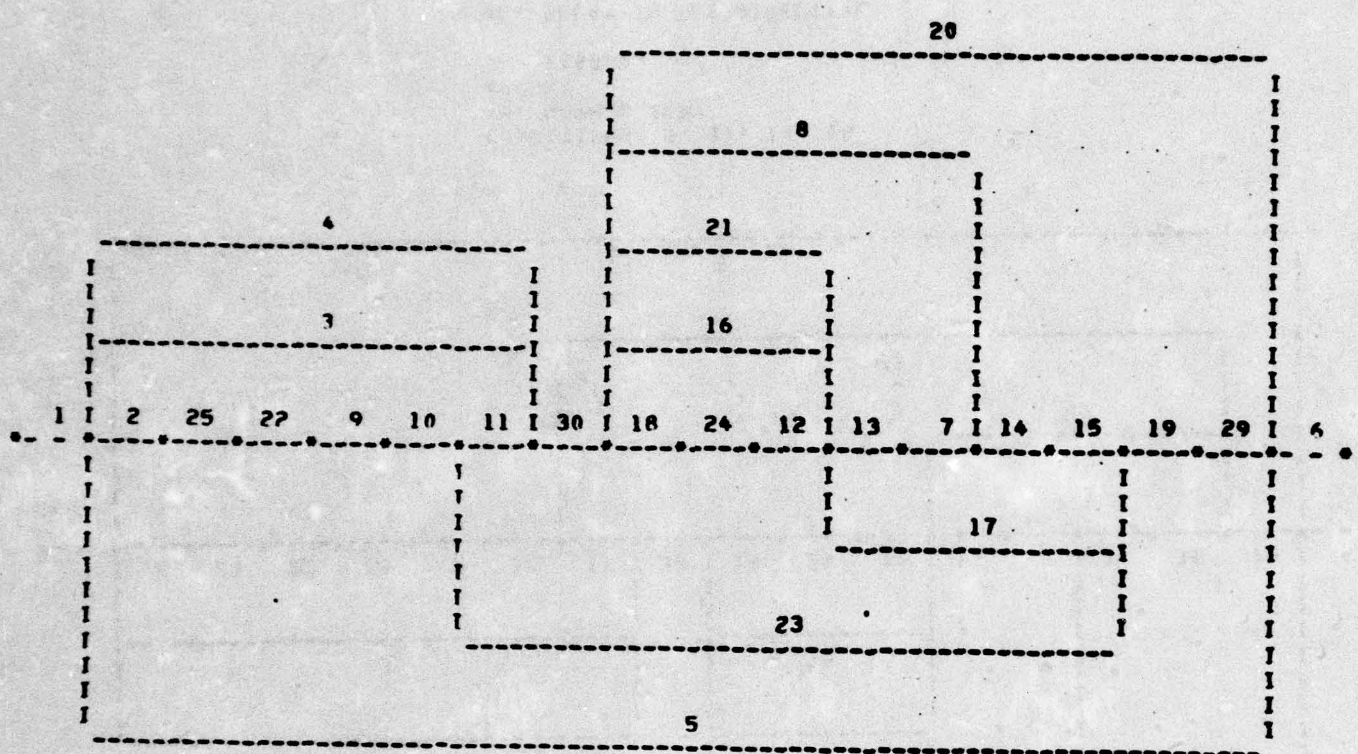
CONDITIONS: 5, 11, 14, 15
AE, NORMAL ARMY
AMOUNT
160000.

AE, DELAY IN NOTICE TO PROCEED

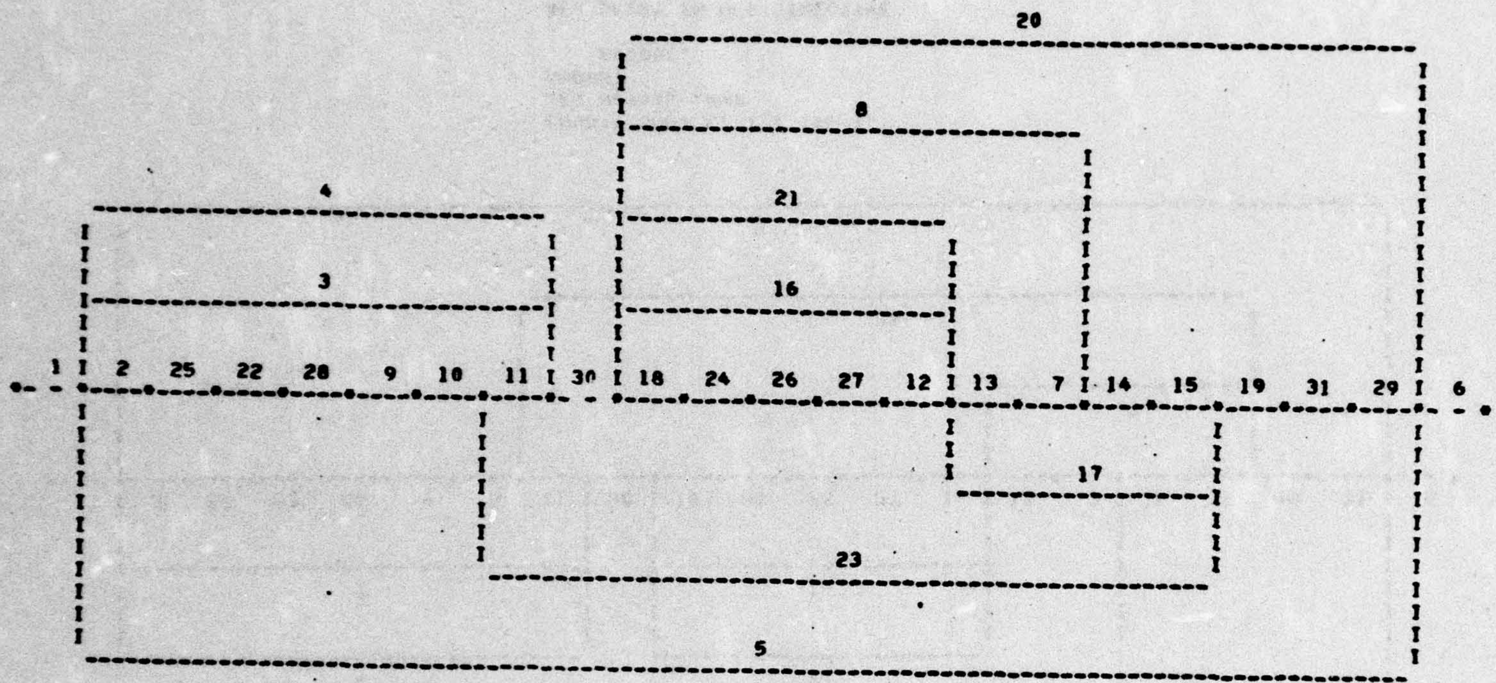


CONDITIONS: 5, 11, 14, 16
AE, NORMAL ARMY
AMOUNT
160000.

AE, DELAY IN DES DIRECTIVE

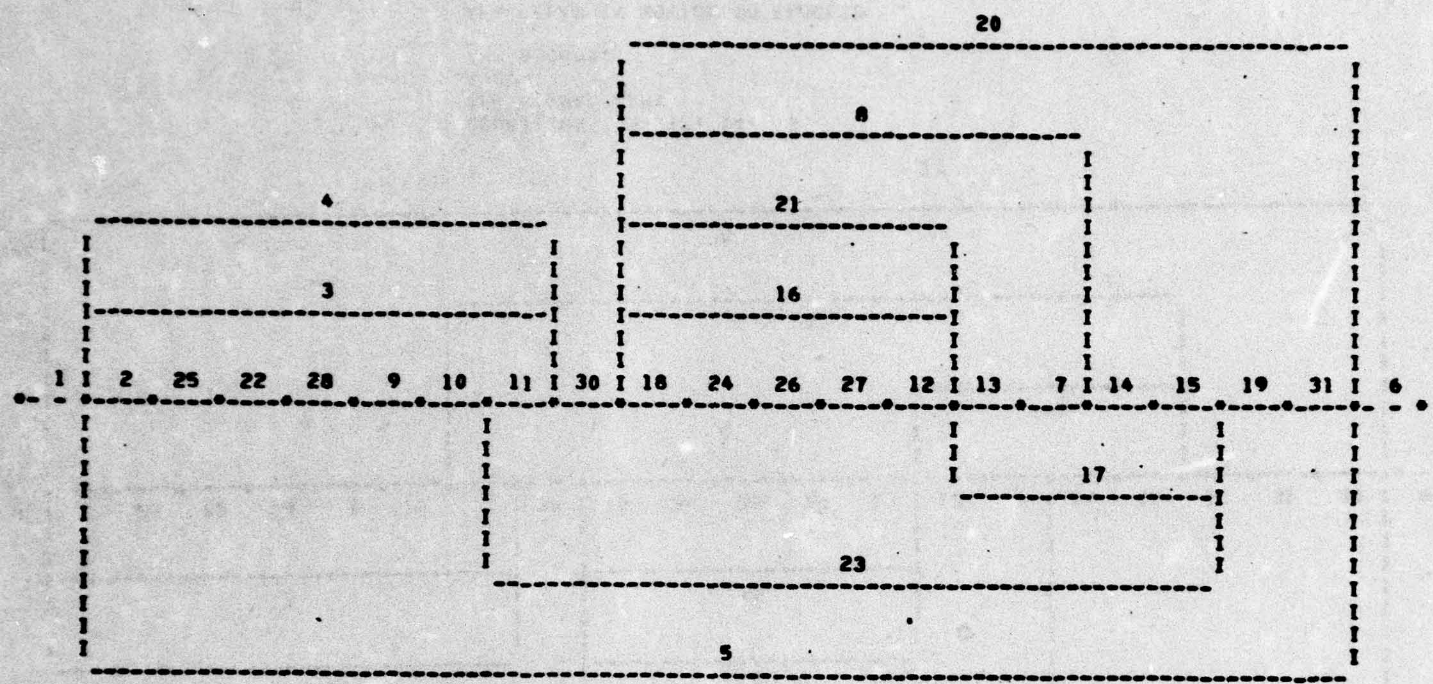


CONDITIONS: 5, 11, 15, 16
AE, NORMAL ARMY
AMOUNT
    160000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



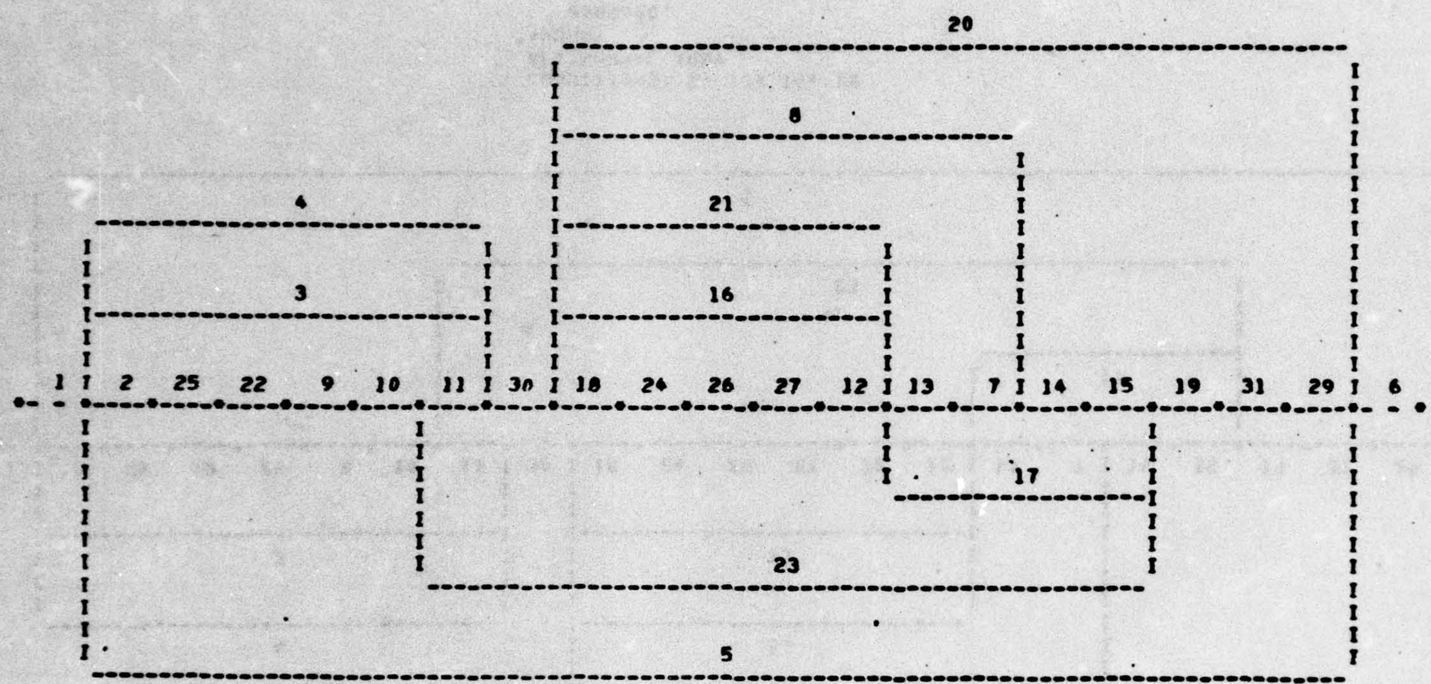
CONDITIONS: 5, 12, 14, 15
AE, NORMAL ARMY
AMOUNT
600000.

AE, DELAY IN NOTICE TO PROCEED

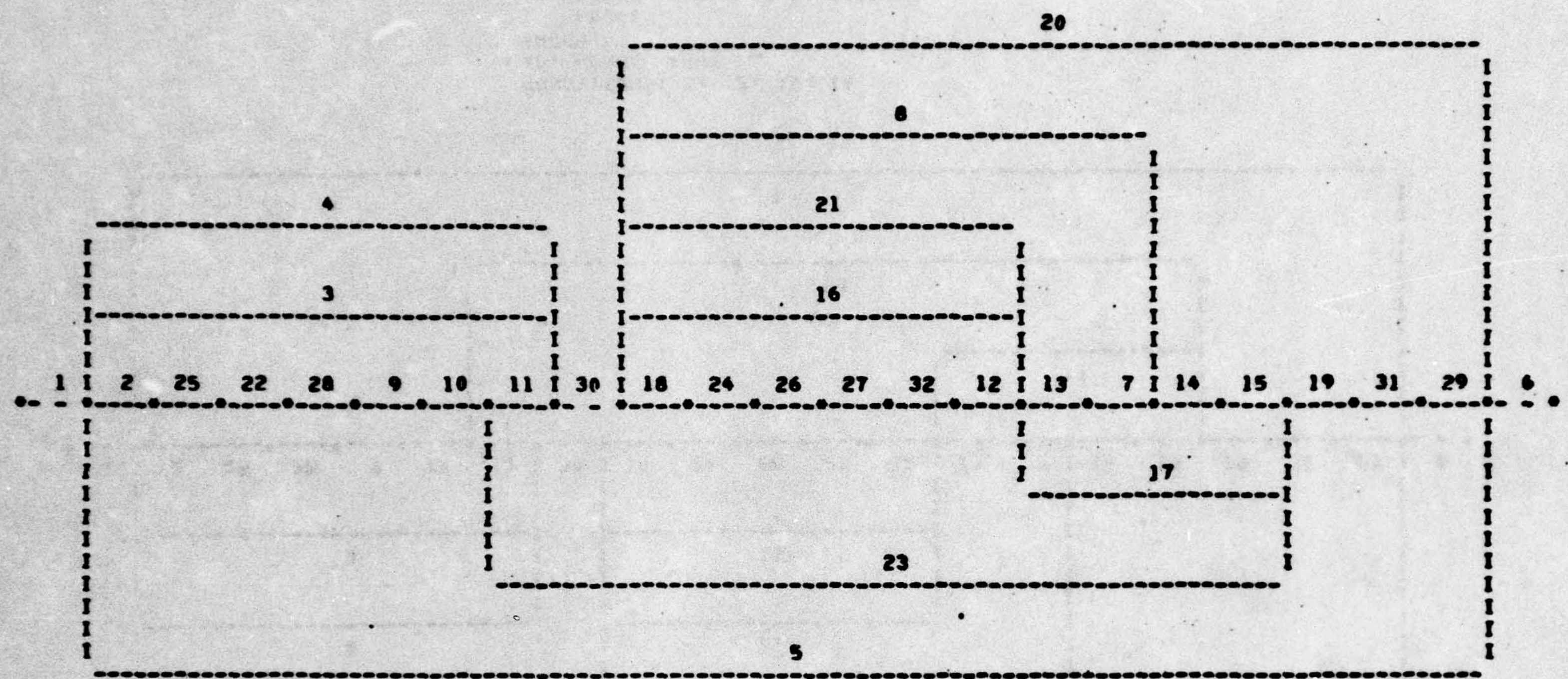


CONDITIONS: 5, 12, 14, 16
AE, NORMAL ARMY
AMOUNT
600000.

AE, DELAY IN DES DIRECTIVE

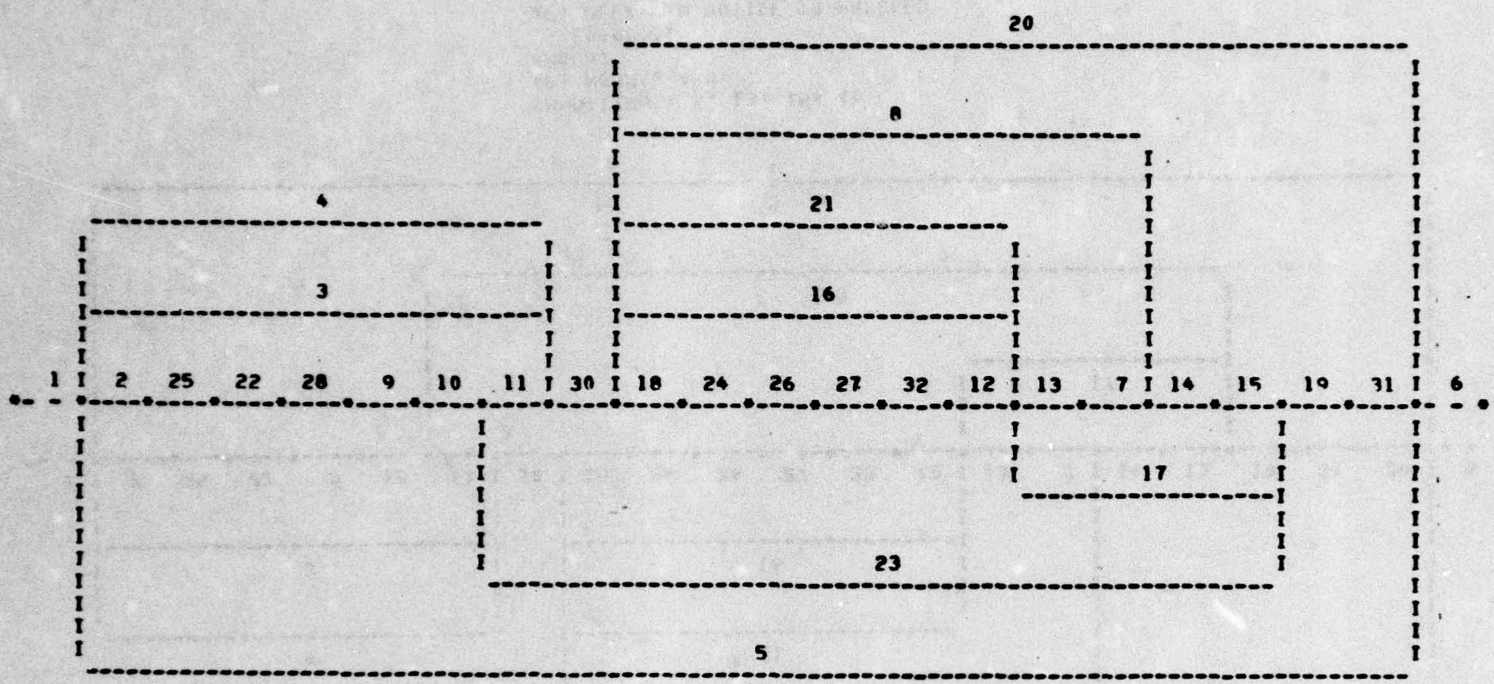


CONDITIONS: 5, 12, 15, 16
AE, NORMAL ARMY
AMOUNT
    600000.
AE, DELAY IN NOTICE TO PROCEED
AE, DFLAY IN DES DIRECTIVE



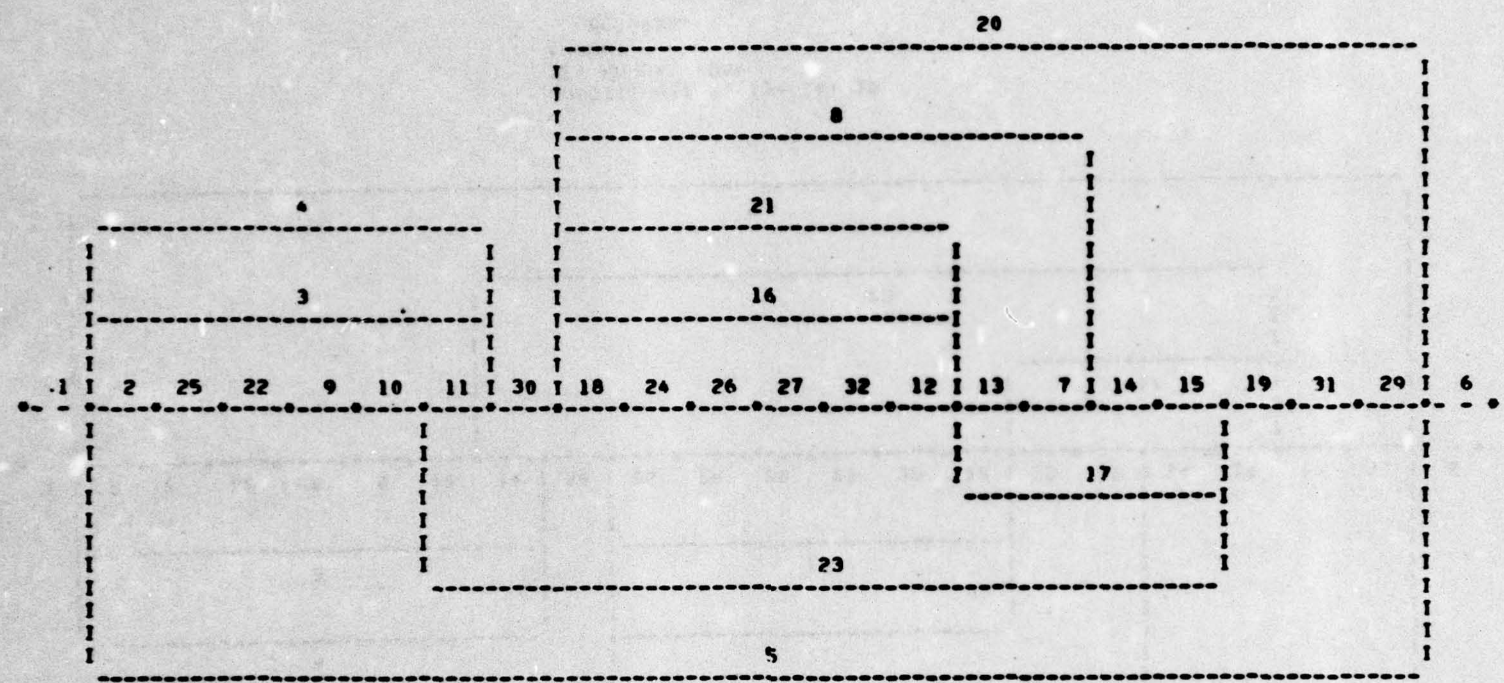
CONDITIONS: 5, 13, 14, 15
AE, NORMAL ARMY
AMOUNT
2000000.

AE, DELAY IN NOTICE TO PROCEED

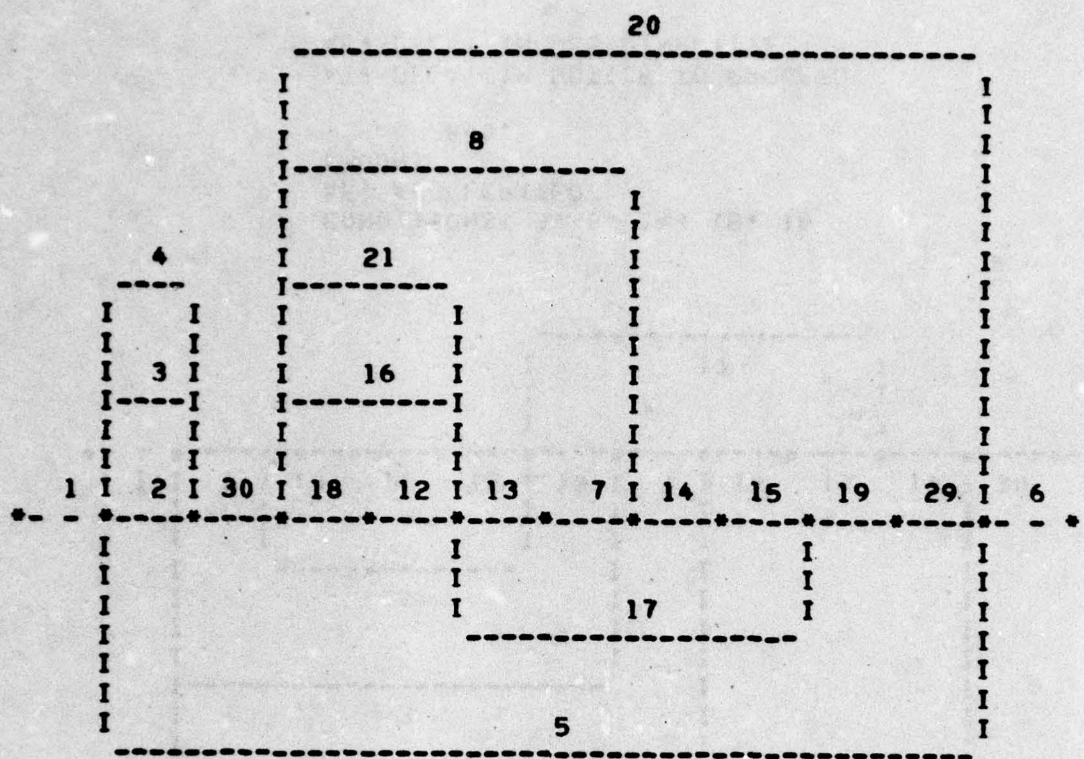


CONDITIONS: 5, 13, 14, 16
AE, NORMAL ARMY
AMOUNT
2000000.

AE, DELAY IN DES DIRECTIVE

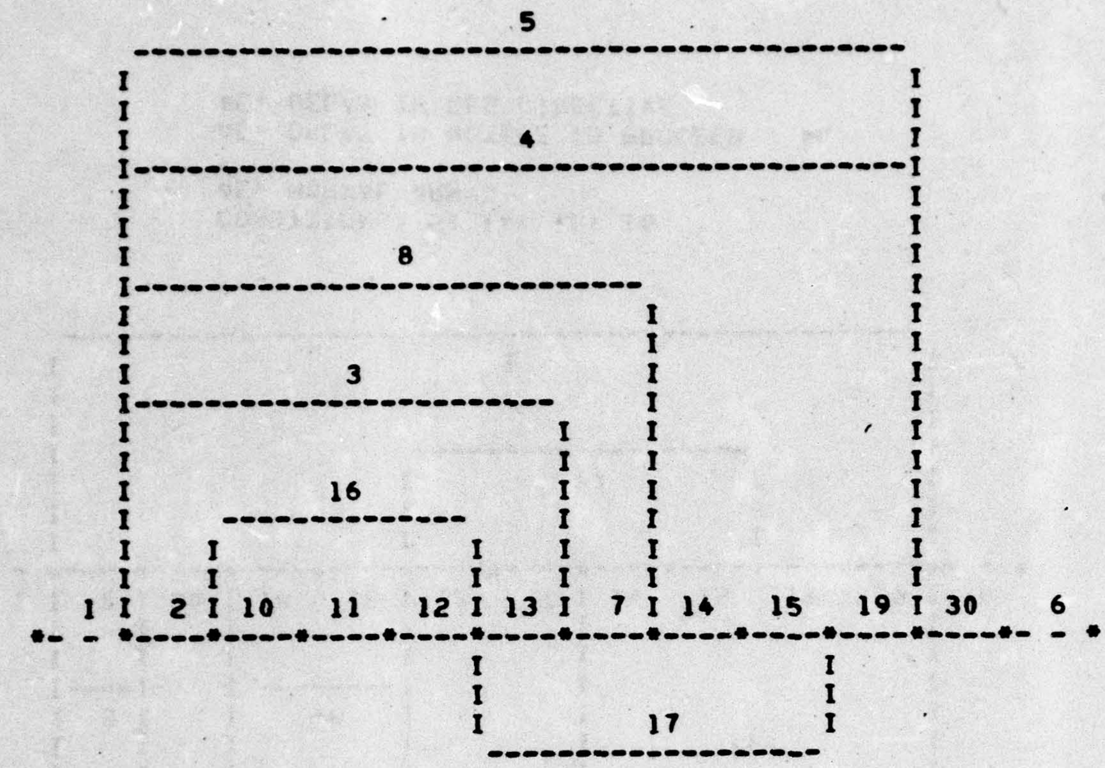


CONDITIONS: 5, 13, 15, 16
AE, NORMAL ARMY
AMOUNT
2000000.
AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



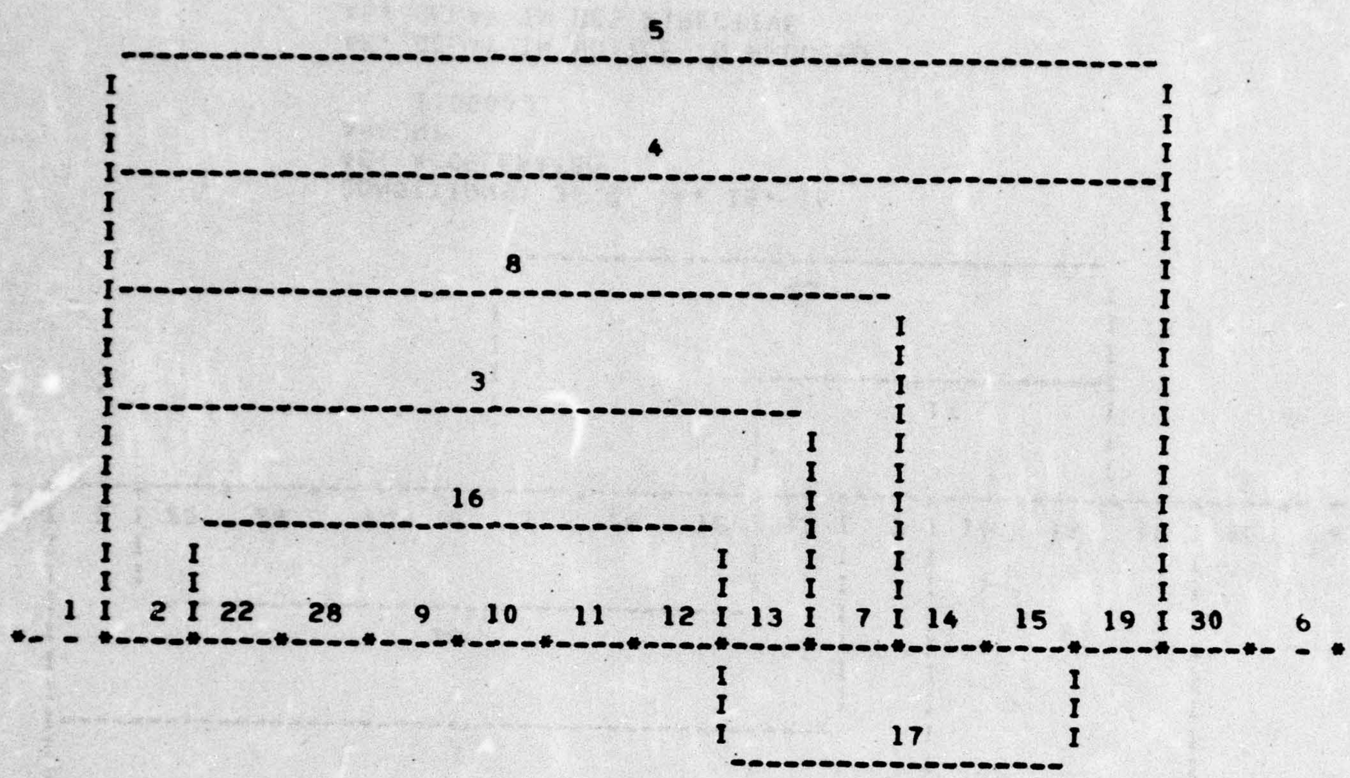
CONDITIONS: 5, 14, 15, 16
AE, NORMAL ARMY

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



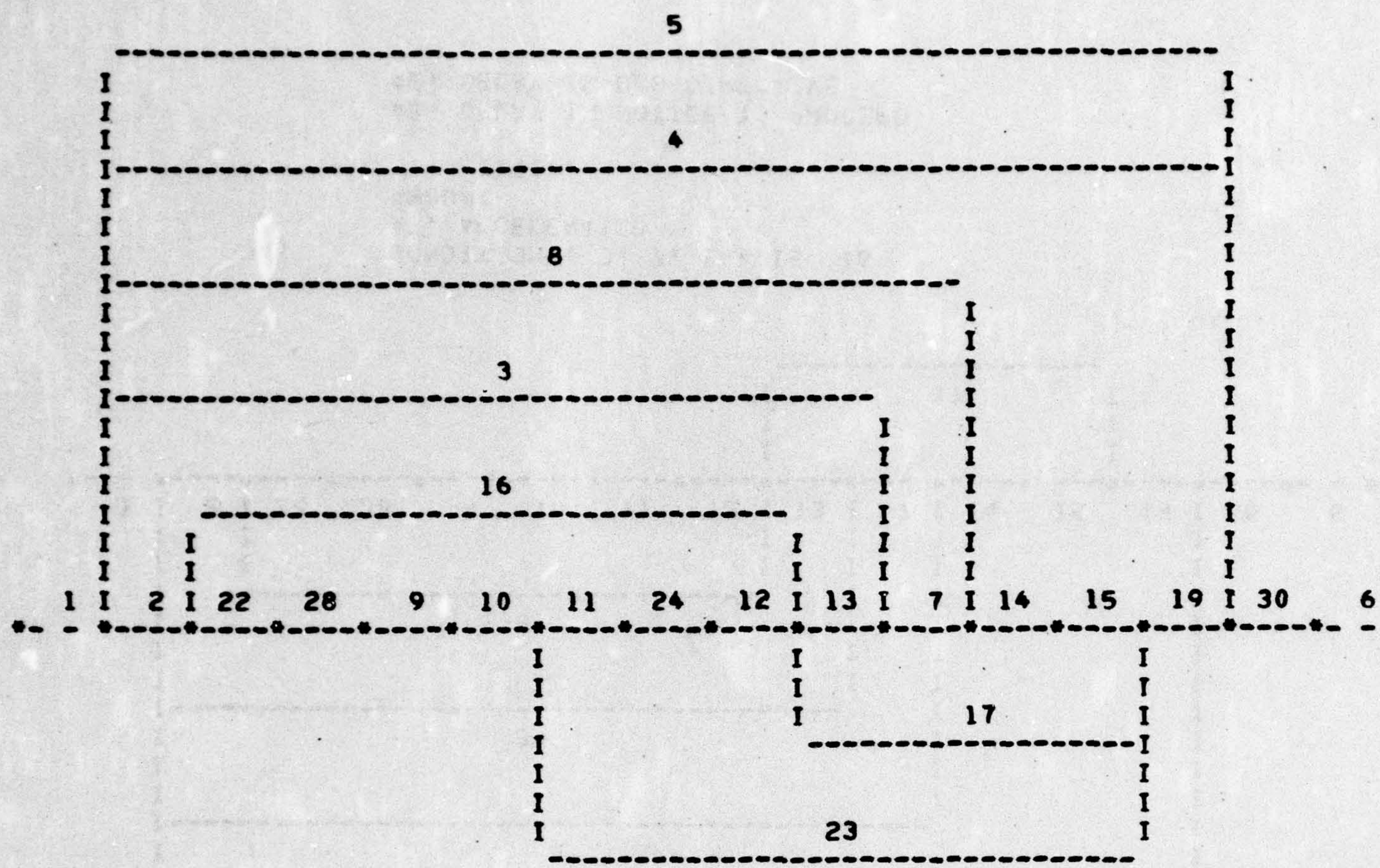
CONDITIONS: 3, 6, 14, 15, 16
AE, ACCELERATED
AMOUNT
2600.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



CONDITIONS: 3, 7, 14, 15, 16
AE, ACCELERATED
AMOUNT
11000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



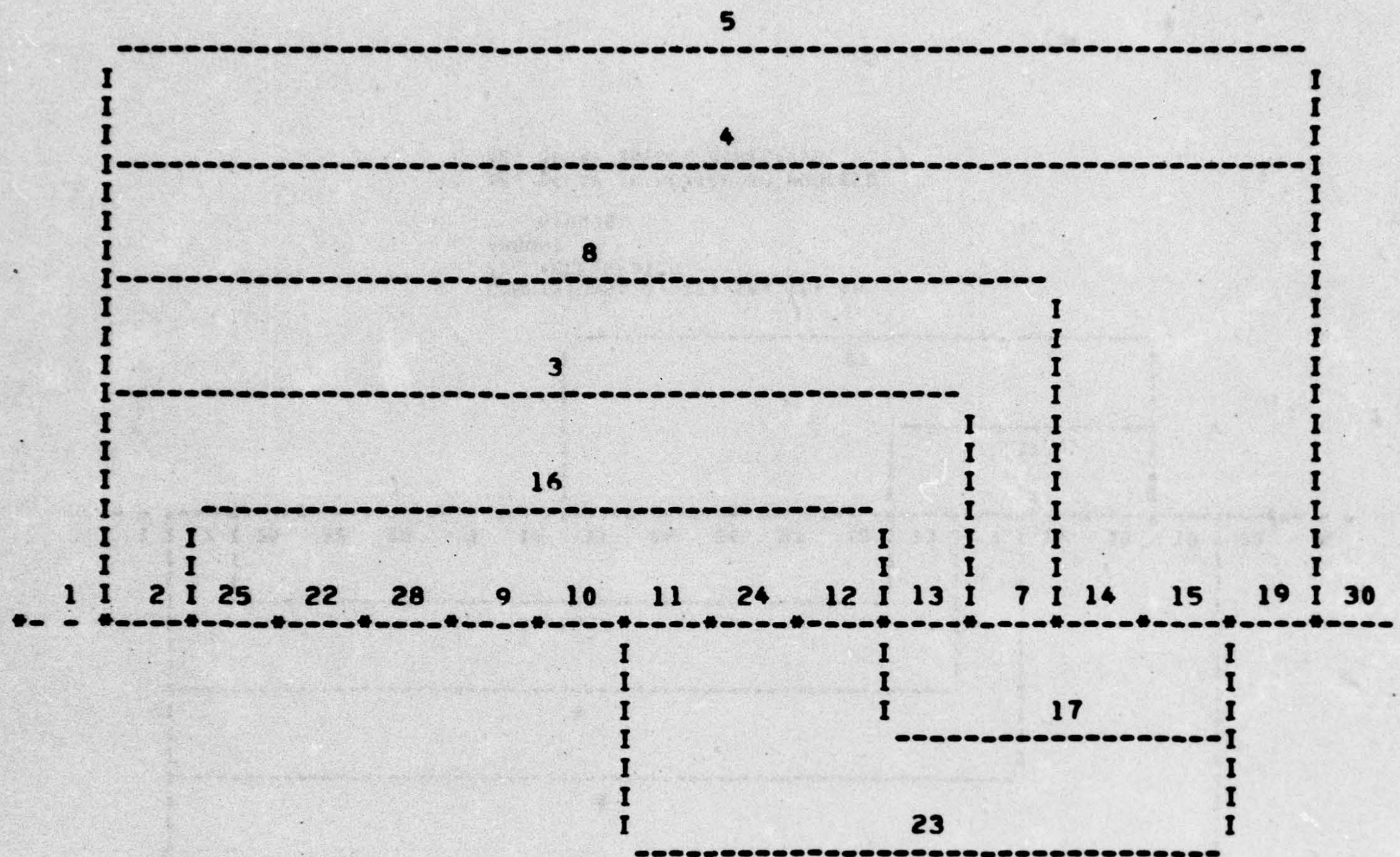
CONDITIONS: 3, 9, 14, 15, 16
AE, ACCELERATED
AMOUNT
110000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE

AD-A035 208 CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAI--ETC F/G 5/1
ENGINEERING AND DESIGN PERFORMANCE ANALYSIS. (U)
DEC 76 R L LAPP, J G KIRBY
UNCLASSIFIED CERL-IR-C-75 NL

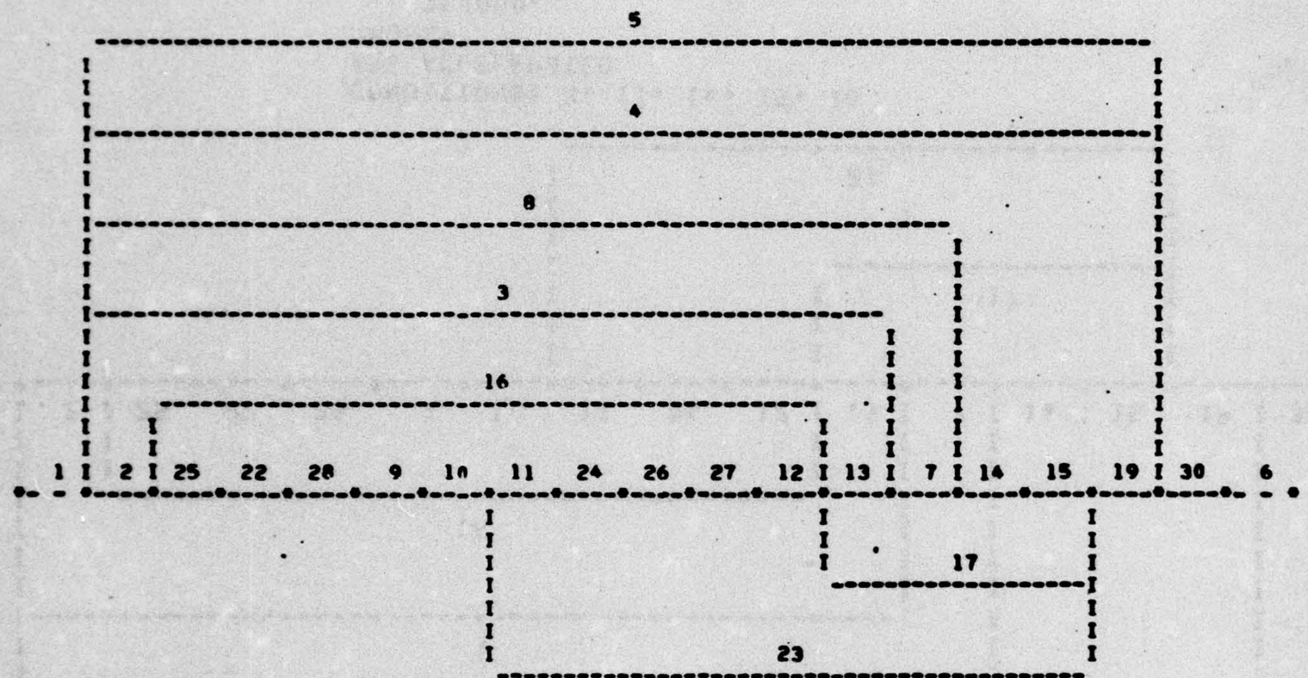
4 OF 4
AD
A035208

END
DATE
FILMED
3-77



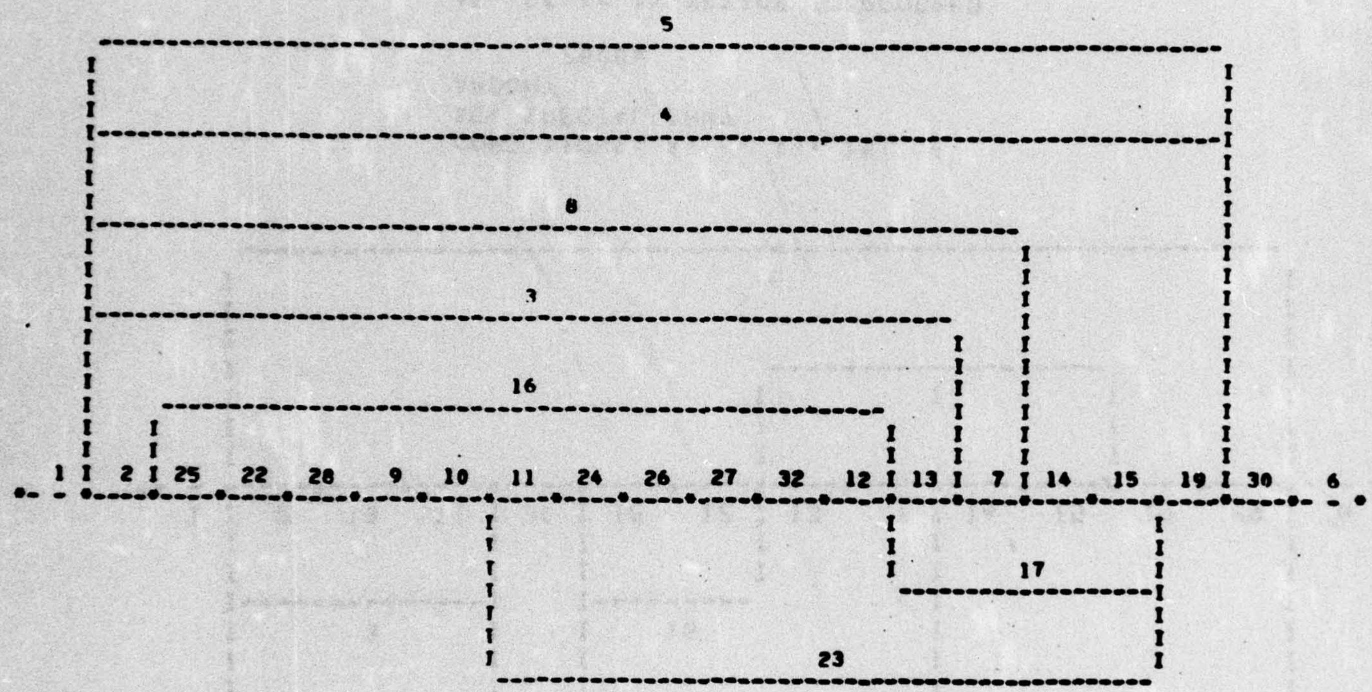
CONDITIONS: 3, 11, 14, 15, 16
AE, ACCELERATED
AMOUNT
160000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



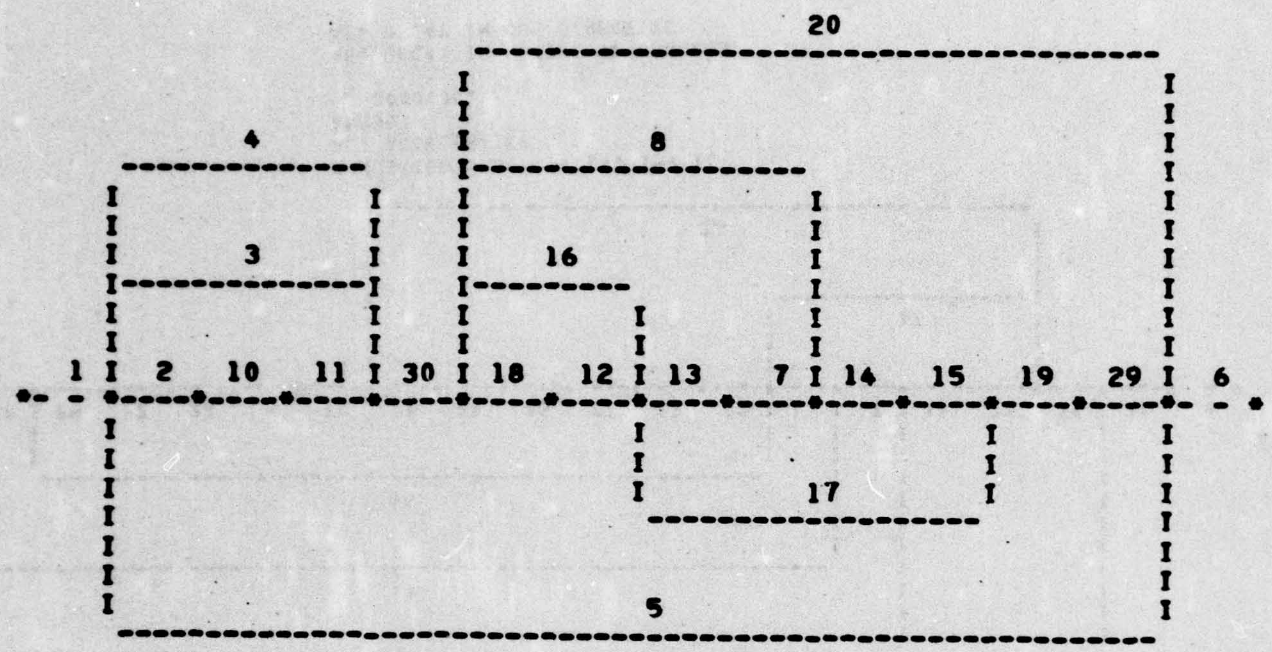
CONDITIONS: 3, 12, 14, 15, 16
AE, ACCELERATED
AMOUNT
600000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



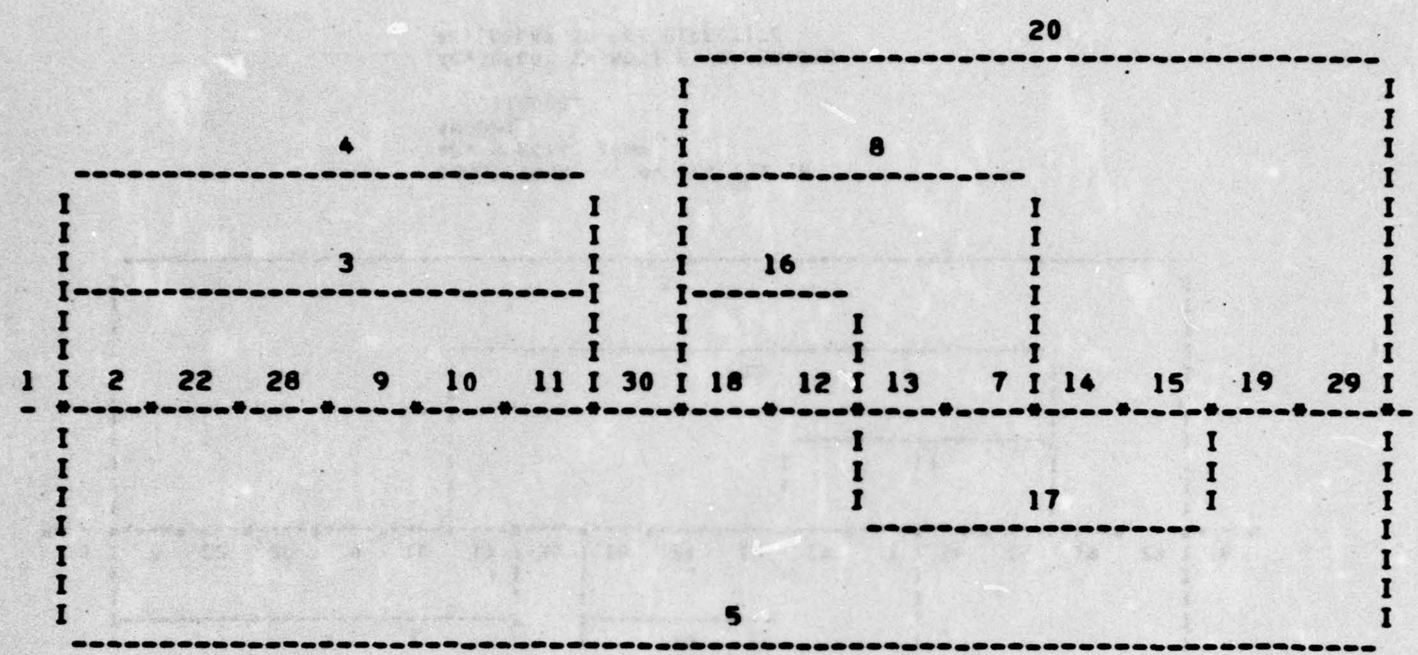
CONDITIONS: 3, 13, 14, 15, 16
AE, ACCELERATED
AMOUNT
2000000.

AE, DFLAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



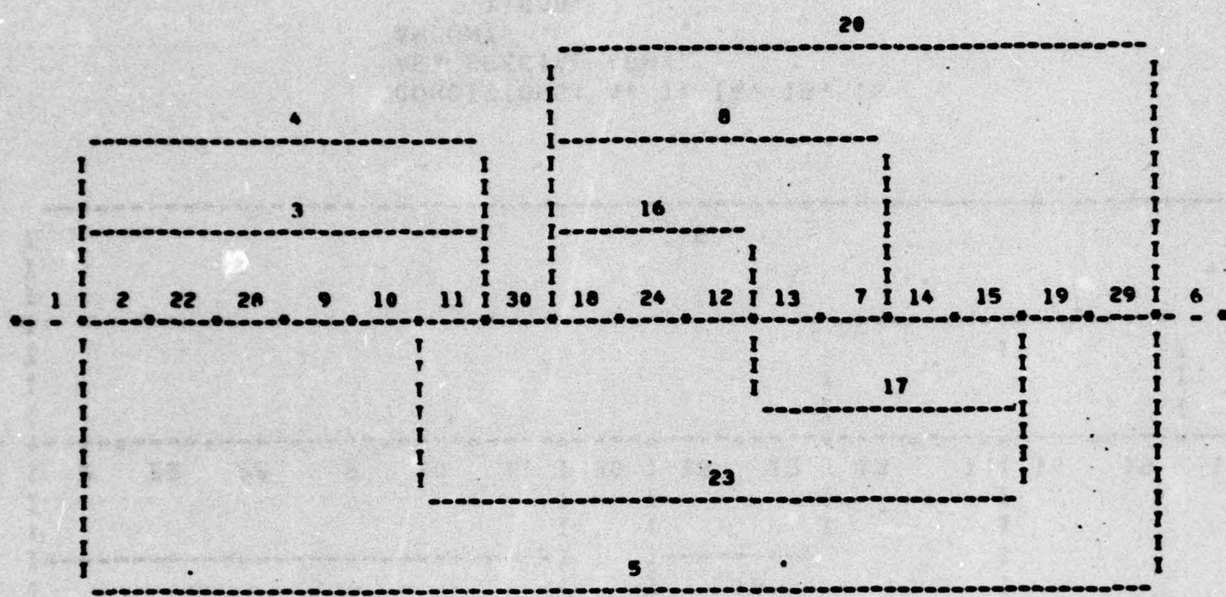
CONDITIONS: 4, 6, 14, 15, 16
AE, SPECIAL ARMY
AMOUNT
2600.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



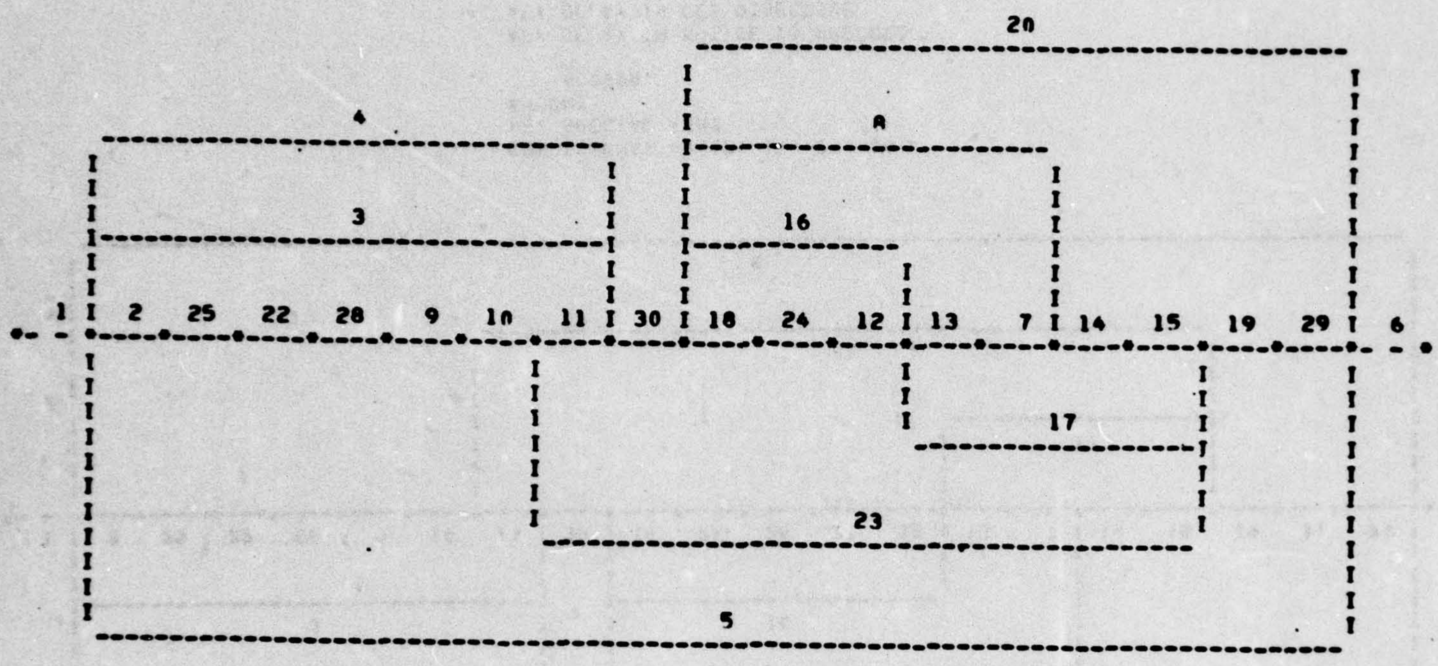
CONDITIONS: 4, 7, 14, 15, 16
AE, SPECIAL ARMY
AMOUNT
11000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



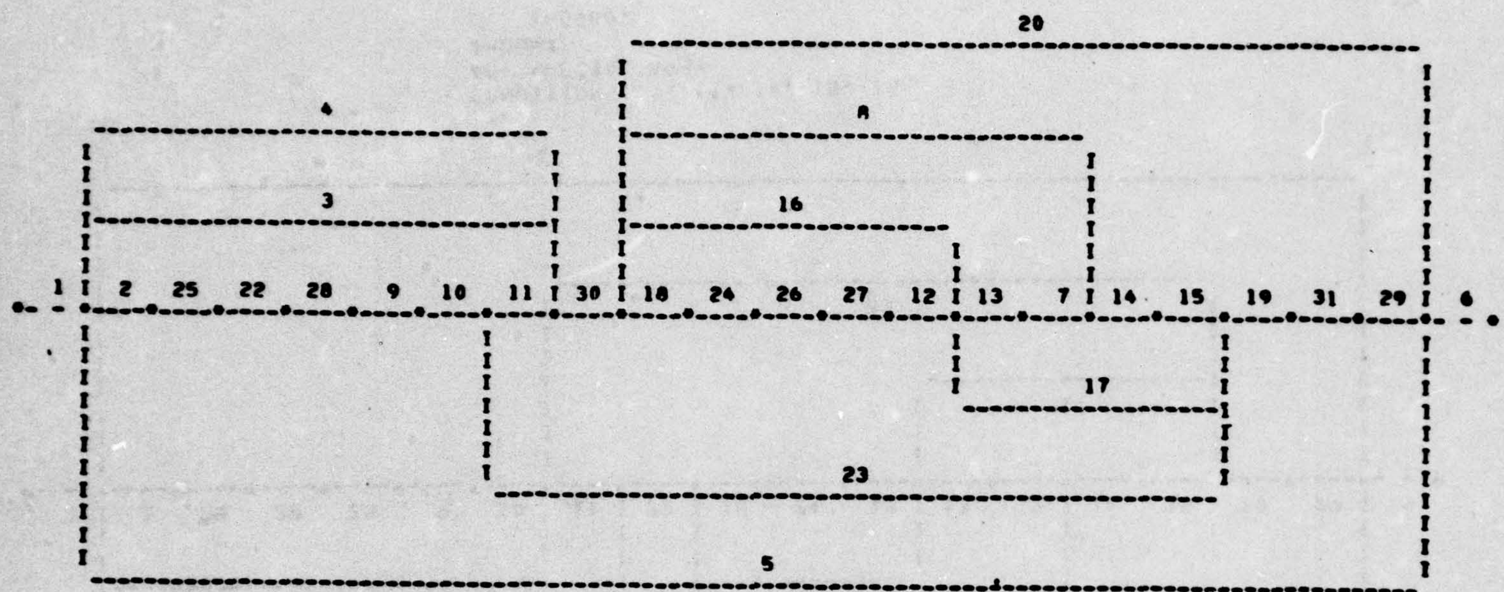
CONDITIONS: 4, 9, 14, 15, 16
AE, SPECIAL ARMY
AMOUNT
110000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



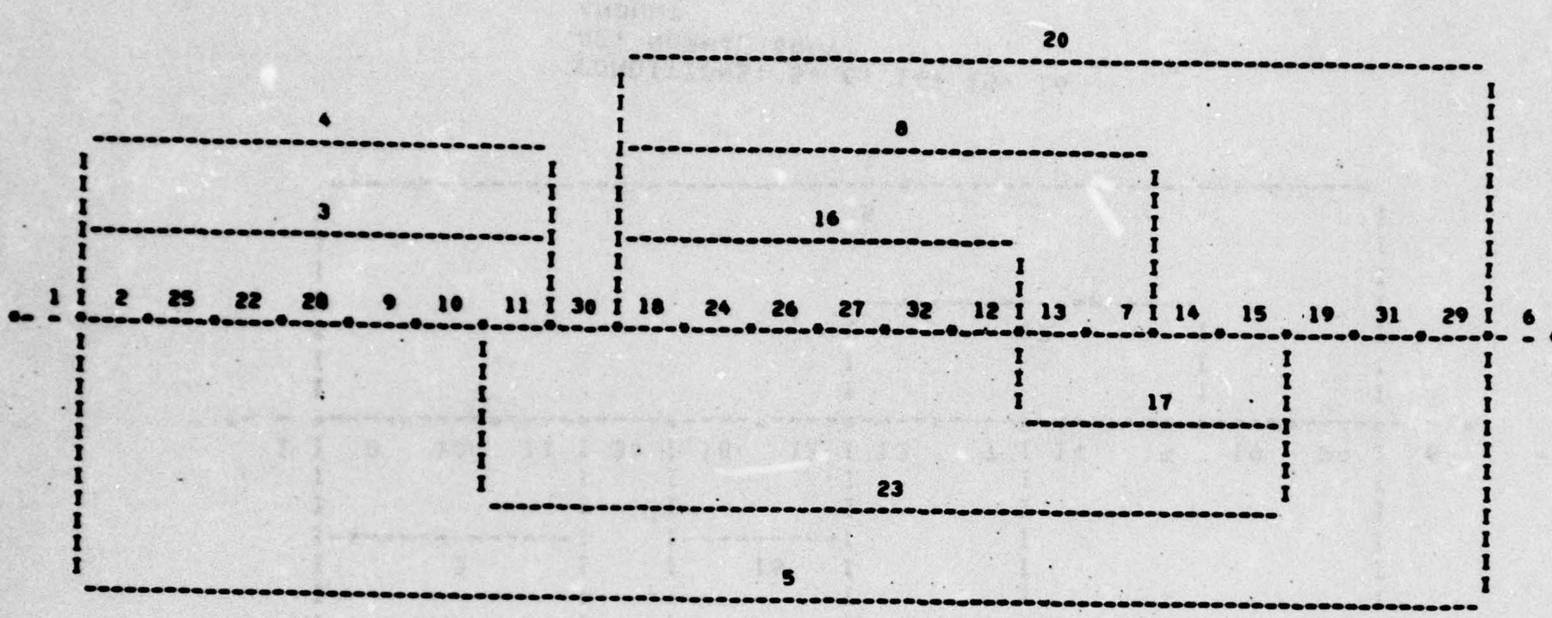
CONDITIONS: 4, 11, 14, 15, 16
AE, SPECIAL ARMY
AMOUNT
160000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



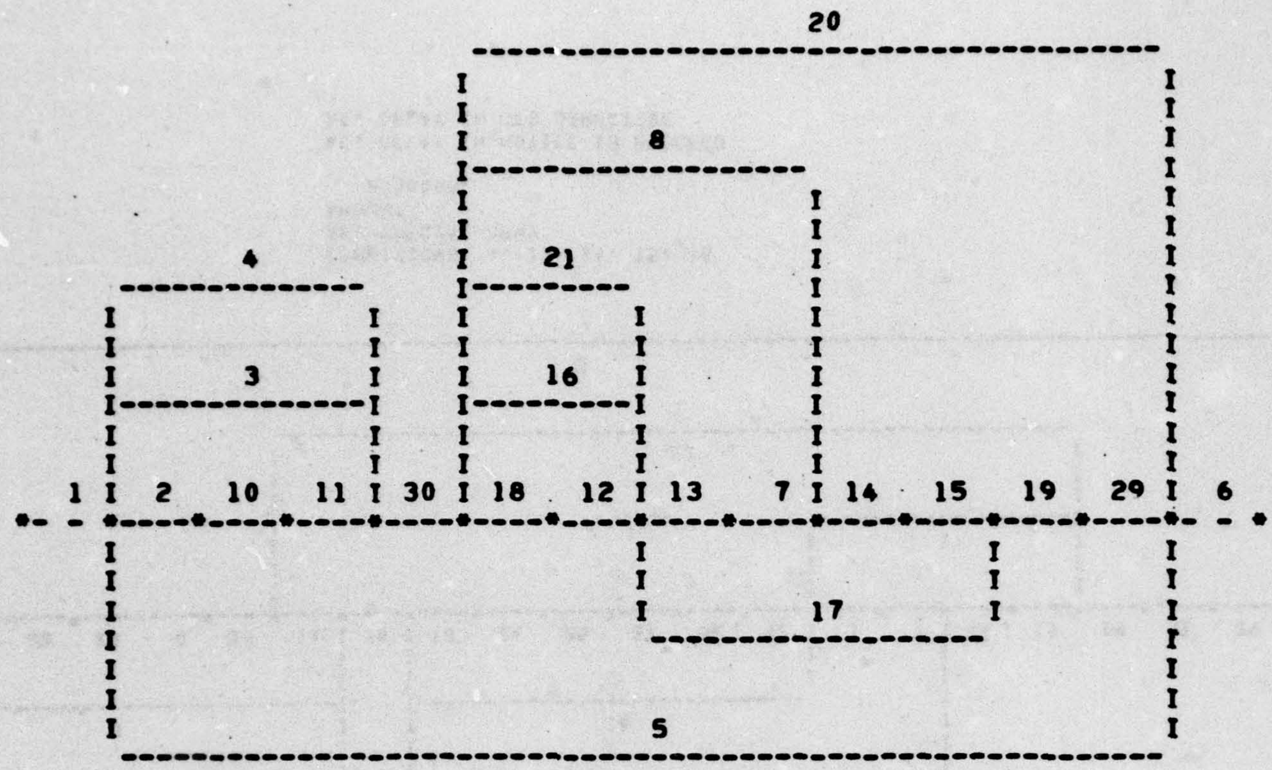
CONDITIONS: 4, 12, 14, 15, 16
AE, SPECIAL ARMY
AMOUNT
    600000.

AE, DFLAY IN NOTICE TO PPOCEED
AE, DELAY IN DES DIRECTIVE



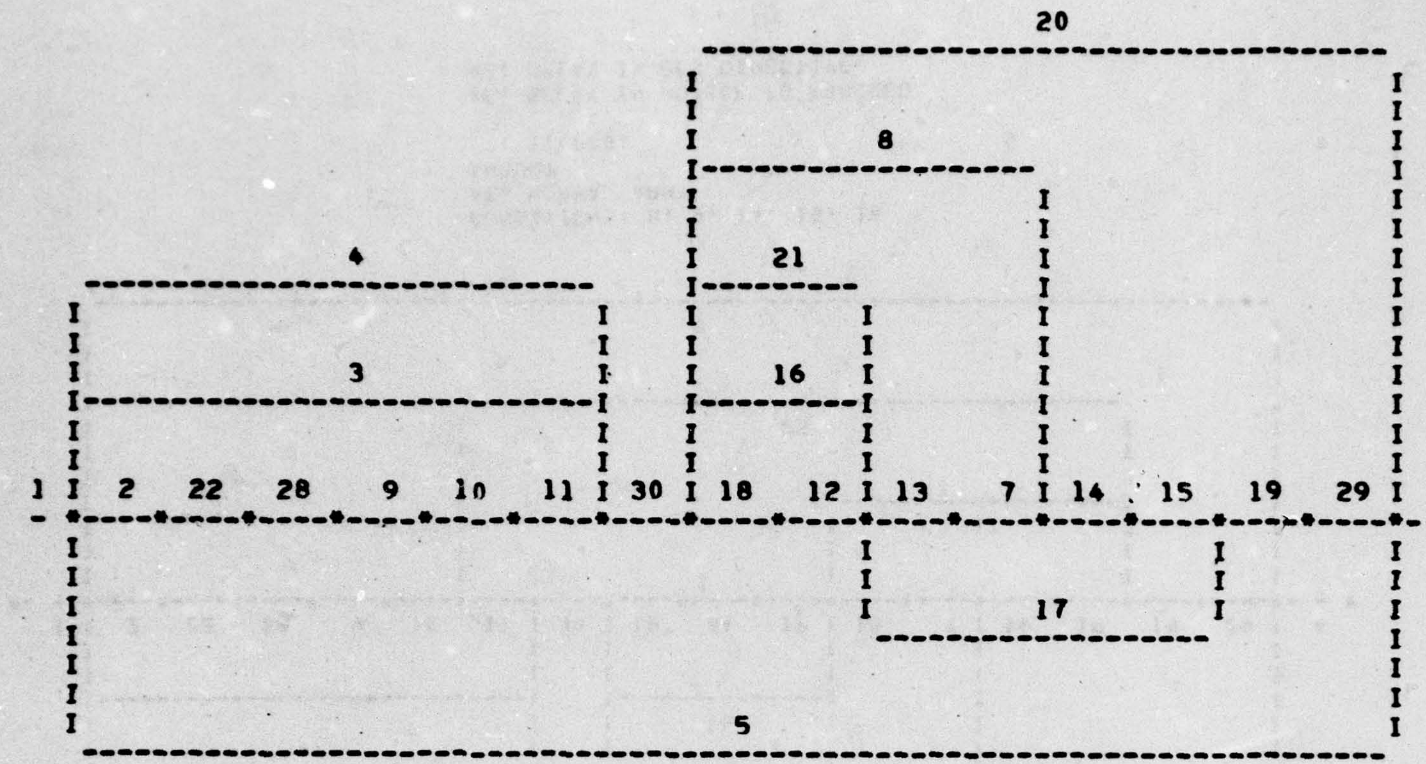
CONDITIONS: 4, 13, 14, 15, 16
AE, SPECIAL ARMY
AMOUNT
2000000.

AE, DFLAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



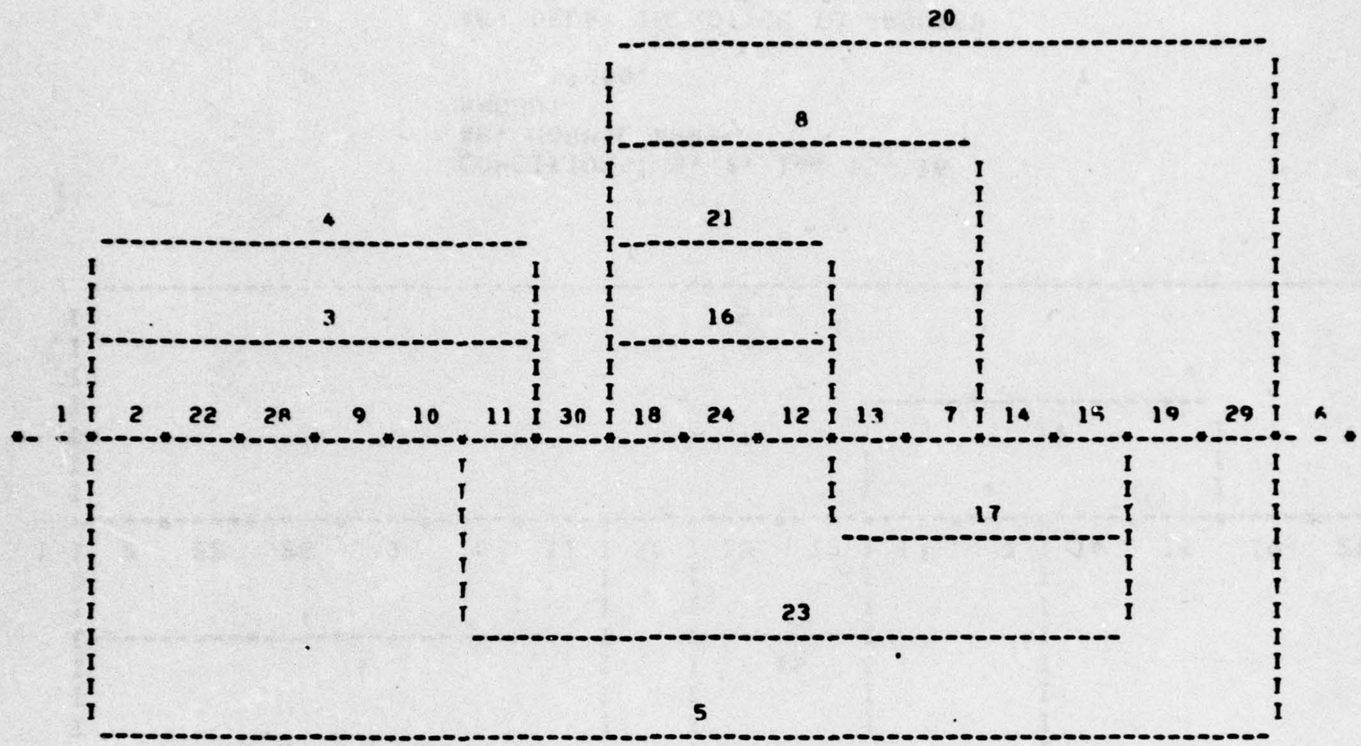
CONDITIONS: 5, 6, 14, 15, 16
AE, NORMAL ARMY
AMOUNT
2600.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



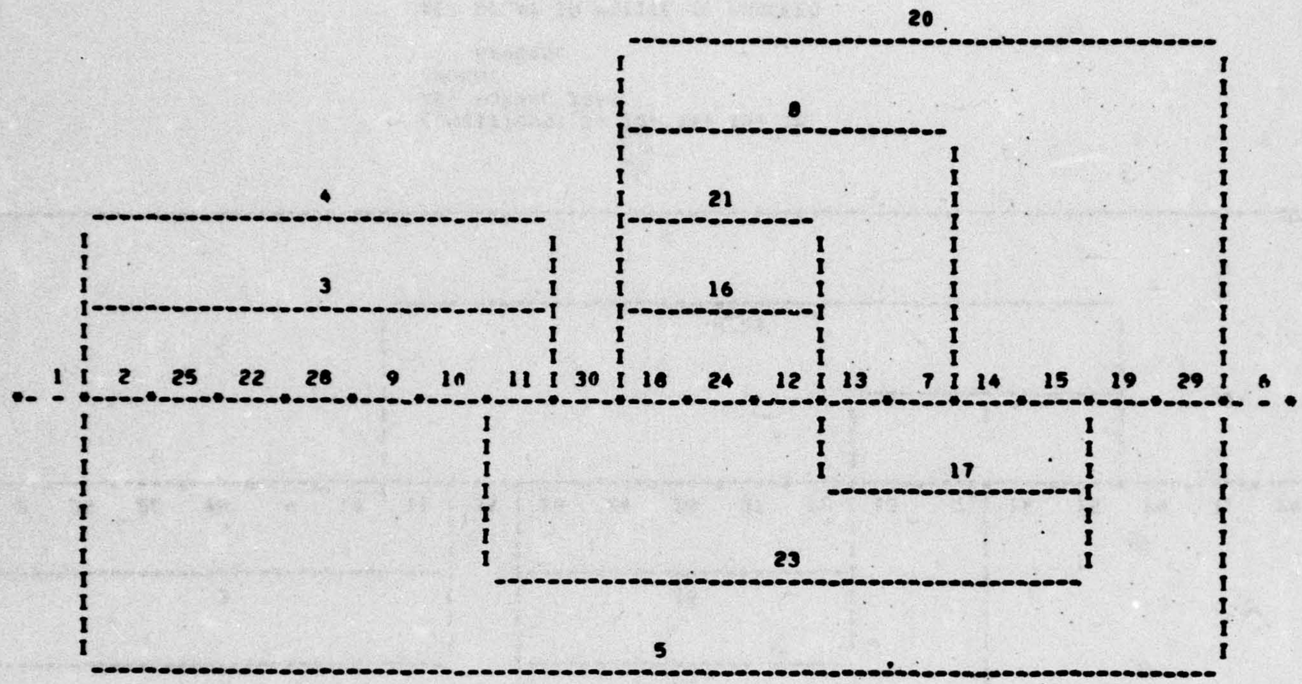
CONDITIONS: 5, 7, 14, 15, 16
AE, NORMAL ARMY
AMOUNT
11000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



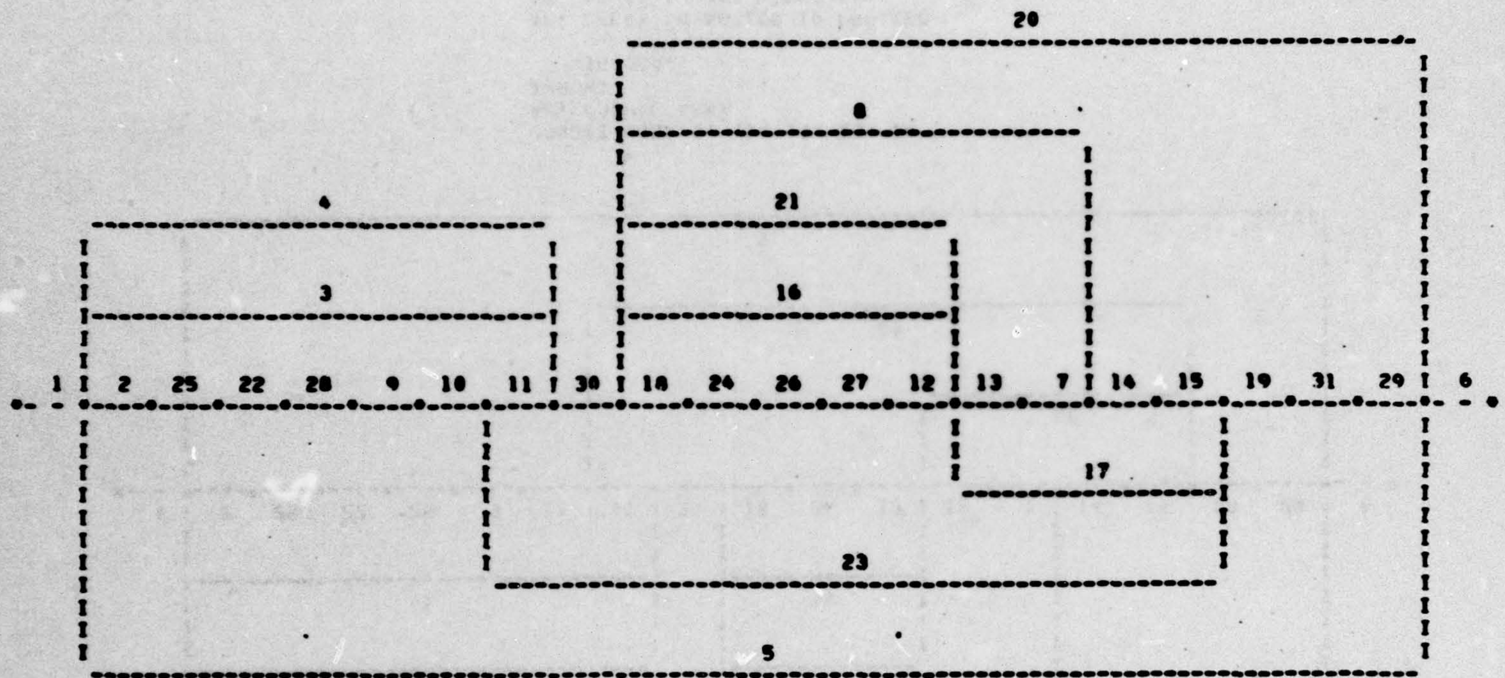
CONDITIONS: 5, 9, 14, 15, 16
AE, NORMAL ARMY
AMOUNT
110000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



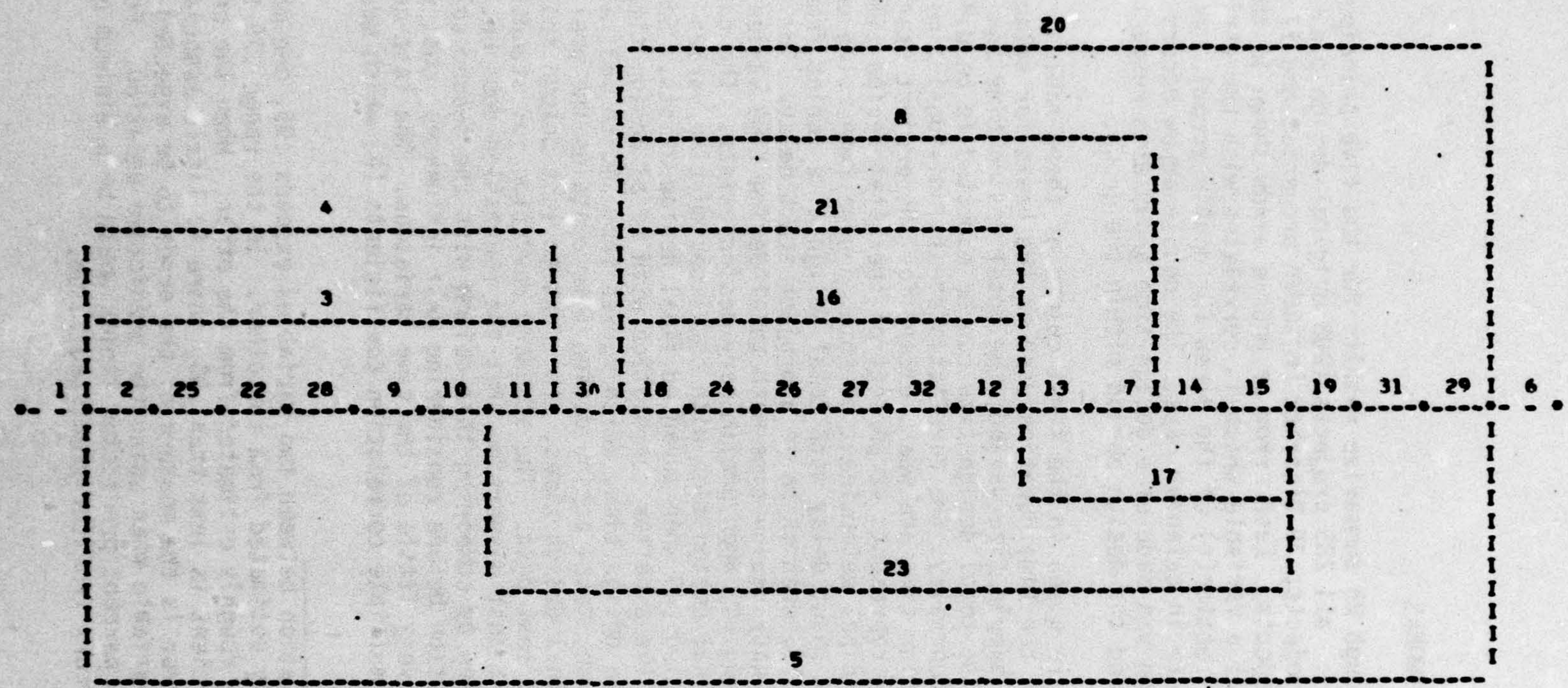
CONDITIONS: 5, 11, 14, 15, 16
AE, NORMAL ARMY
AMOUNT
    160000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



CONDITIONS: 5, 12, 14, 15, 16
AE, NORMAL ARMY
AMOUNT
600000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE



CONDITIONS: 5, 13, 14, 15, 16
AE, NORMAL ARMY
AMOUNT
2000000.

AE, DELAY IN NOTICE TO PROCEED
AE, DELAY IN DES DIRECTIVE

APPENDIX B:

A/E PROCUREMENT NETWORKS

Tables B1 through B5 summarize results for the five principal sets of regressions: all 285 projects (208 original design projects); 200 A/E-designed projects; 79 District Engineer projects; and 77 non-original design projects. Each arrow or double arrow shown in the tables is located at a variable which is correlated with the string of variables in the direction(s) of the arrow (or double arrow). All time calculations are in calendar days. The double arrow occurs when a second correlation was made of a design time group with respect to total design time and the design period within the group.

Sample sizes are given in the first column of these tables. The second column shows the time duration used as the basis for selecting the sample. Since sample size varied, the total design time and standard deviation of the total design time can be expected to be different for each sample. Generally, the correlations* of individual time periods with total design time are weak, except for the project start delay period, which represents 42 percent of the total design time and therefore is a principal determinant of total design time. The correlation of project start delay with total design time varies from .58 to .81, averaging .76, when there is a project start delay. The correlation of preliminary design time with total design time varies from .27 to .50, averaging .41 when preliminary design exists. The correlation of advanced final design time with total design time varies from -.01 to .50, averaging .40 when advanced final design exists. Some groups of periods give a better correlation with total design time, notably total active design time, which varies from .44 to .63, averaging .54. Of course, total active design time contains the preliminary and advanced final design times. The next-to-last column shows the dispersion in total cost data. The standard deviation (or standard error) indicates the cost dispersion that the regression does not remove. As can be seen by comparing this column with the second column (the standard deviation before considering cost influence), cost variation accounts for very little of the time variation. The last column shows the computed multiple correlation coefficients (R) which measure

---

* When the correlation between two variables exceeds .95, one may be quite accurately estimated from the other. In the range .75 to .85, one may be roughly estimated from the other. When the correlation coefficient is less than .35, there is little association. The standard error is the measure of the error to be expected of the dependent variable when using the predictive equation. For example, the 95 percent prediction limits would be a minimum of ± 2 standard errors from the predicted value.

how strongly total design time, total design cost, total design cost squared, (and, as applicable, total design cost to the third and fourth powers and exp[-C/M] are related. R^2, expressed as a percent, is a measure of the total design time variation explained by the equation. Referring to Table B4, the total active design time is seen to have an R value of .66; $100(.66)^2$ = 44 percent of the variation in time before regression is due to cost variation, resulting in a drop from 147 calendar days standard deviation before regression to 114 days afterwards, 147 - 114 = 33 days accounted for by cost variation.

Table B6 shows the ratio of standard deviation to mean time for design periods and shows period groups for the five principal project groups. The ratios of standard deviation and mean time are relatively high because the standard deviations include dispersions caused by project size.

Table B7 shows the results of the time versus cost regressions; these are presented in terms of means and standard deviations of design time and design cost for groups of design periods within each of the five principal groups of projects. Within a project group, such as the 79 District Engineer projects, differences in design period group samples become evident; the mean time varies from 391 to 496 calendar days, the time standard deviation varies from 184 to 233 days, the mean cost varies from $41,446 to $62,072 and the cost standard deviation varies from $42,447 to $48,966.

Table B8 shows the dispersion in total design time data that could not be accounted for by regression with total design cost data. The main diagonal of the 5 x 5 array contains the regression results.

Generally, the standard deviation (or standard error) of total design time is a little less than the mean total design time. For all 70 projects, the figures are 177 and 198 days, respectively. However, all but 62 of the 177 days can be accounted for after regression has removed the variation in time related to variation in cost. The first line of the array shows the effect of applying the time-cost equation for all 70 projects to other sample groups of projects. The equation for all projects works quite well for all except the small airfield-paving projects. The 33 days unaccounted for in the 14 two-phase projects are determined by taking the square root of the mean square of the differences between the actual and theoretical design times. The equation for all 70 projects was used to determine theoretical design times for the 14 two-phase projects. The mean square is the sum of the squares of the differences, divided by the degrees of freedom of the residual--11 in this case (14 projects, less the mean value used, less two degrees of freedom of regression). The first column of the array shows the effect of applying individual time-cost equations to all 70 projects. As expected, this does not work well where the equation was determined by a small sample which is characteristically

different from the entire group. The 361 days unaccounted for by using the 14 two-phase projects is, again, the square root of the mean square of the differences between the actual and theoretical design times. In this case, the residual had 12 degrees of freedom.

The total design-time scope equations did not fit quite as well as the total-design-time total-design-cost equations. In the time scope equations, the standard deviation after regression removed variation was 175 days for 15 building projects and 55 days for five airfield-paving projects, as contrasted with 112 and 18 days, respectively, in the time-cost equations. Of course, time scope relations are of greater interest if they can be established, since they are largely time-independent, unlike time-cost relations which, to eliminate time dependence, depend on cost data adjusted to a common base year prior to analysis. Variance not accounted for by regression can be explained in a number of ways. Some variance is inherent in the process and not removable. Some variance could be removed if sufficient data were available--e.g., variance due to productivity trends, seasonal fluctuations, business cycles, and other factors.

Table B1

Time and Cost Regression Results - Adjusted Costs -
All 285 Projects

No. Projs	Dur ≠0	Total Design Time / Design Time Group / Design Period	Time vs. Time: Mean Days	Time vs. Time: Std Dev Days	Time vs. Time: Correl Coeff	Time vs. Cost: Std Dev Days	Time vs. Cost: Correl Coeff
285	X	Total Design Time	421	283	↓	264	.38
		Total Active Design	169	118	.54	101	.52
		Study	12	47	.01		
		Preliminary	47	62	.37		
		Advanced Final	84	65	.41		
		Final	26	52	.26		
		Total Design Review	50	81	.34	80	.18
		Preliminary	28	40	.29		
		Advanced Final	22	68	.24		
		Total Design Delay	202	228	.84	228	.11
		Project Start	176	206	.78		
		Before Preliminary	16	59	.40		
		Before Adv Final	10	30	.25		
285	X	Total Design Time	421	283	↓		
		Project Start Delay	176	206	.78		
		Study and Delay	28	81	.30		
		Prelim, Review, Delay	85	99	.43		
		Adv Fin, Review, Final	132	116	.49		
256		Total Design Time	456	275	↓		
	X	Project Start Delay	196	208	.76	209	.03
35		Total Design Time	421	168	↓ .34		
		Study and Delay	160	115	.34 ↕	115	.22
	X	Study Design	94	101	.07 .77		
		Delay Before Prelim	66	75	.43 .50		
163		Total Design Time	473	279	↓ .54		
		Prelim, Review, Delay	150	86	.54 ↕	81	.33
	X	Preliminary Design	82	61	.41 .69		
		Preliminary Review	49	41	.27 .60		
		Delay Before Adv Fin	19	38	.26 .50		
255		Total Design Time	440	276	↓ .45		
		Adv Fin, Review, Final	143	99	.45 ↕	94	.34
	X	Adv Final Design	94	62	.40 .66		
		Adv Final Review	20	37	.18 .56		
		Final Design	29	54	.25 .71		
135		Total Design Time	515	235	↓		
	X	Final Design	55	64	.20	62	.21
137		Total Design Time	367	242	↓		
	X	Advertisement, Award	116	70	-.06	70	-.10

Table B2

Time and Cost Regression Results - Adjusted Costs - 208 Original Design Projects

No. Projs	Dur ≠0	Total Design Time / Design Time Group / Design Period	Time vs. Time: Mean Days	Time vs. Time: Std Dev Days	Time vs. Time: Correl Coeff	Time vs. Cost: Std Dev Days	Time vs. Cost: Correl Coeff
208	X	Total Design Time	430	282		262	.39
		Total Active Design	175	120	.53	107	.46
		Study	12	53	-.01		
		Preliminary	44	61	.50		
		Advanced Final	91	68	.42		
		Final	28	50	.21		
		Total Design Review	54	90	.35	89	.13
		Preliminary	30	41	.28		
		Advanced Final	24	78	.26		
		Total Design Delay	201	218	.83	217	.16
		Project Start	179	191	.77		
		Before Preliminary	13	59	.49		
		Before Adv Final	9	23	.22		
208	X	Total Design Time	430	282			
		Project Start Delay	179	191	.77		
		Study and Delay	25	82	.34		
		Prelim, Review, Delay	83	99	.48		
		Adv Fin, Review, Final	143	121	.49		
196		Total Design Time	445	280			
	X	Project Start Delay	190	191	.77	191	.13
21		Total Design Time	389	169	.29		
		Study and Delay	155	134	.29	138	.19
	X	Study Design	122	122	.17 .93		
		Delay Before Prelim	33	50	.35 .41		
111		Total Design Time	523	275	.46		
		Prelim, Review, Delay	156	83	.46	81	.24
	X	Preliminary Design	83	61	.50 .71		
		Preliminary Review	55	42	.09 .61		
		Delay Before Adv Fin	18	29	.13 .49		
197		Total Design Time	426	281	.50		
		Adv Fin, Review, Final	145	102	.50	97	.31
	X	Adv Final Design	95	66	.48 .68		
		Adv Final Review	21	40	.20 .57		
		Final Design	29	51	.22 .67		
103		Total Design Time	491	225			
	X	Final Design	56	59	.19	59	.15
105		Total Design Time	392	227			
	X	Advertisement, Award	122	76	-.06	76	-.11

Table B3

Time and Cost Regression Results - Adjusted Costs - 200 Architect-Engineer Projects

No. Projs	Dur ≠0	Total Design Time / Design Time Group / Design Period	Time vs. Time: Mean Days	Time vs. Time: Std Dev Days	Time vs. Time: Correl Coeff	Time vs. Cost: Std Dev Days	Time vs. Cost: Correl Coeff
200	X	Total Design Time	422	287		267	.40
		Total Active Design	156	103	.63	88	.54
		Study	10	42	.02		
		Preliminary	47	58	.42		
		Advanced Final	77	58	.52		
		Final	22	40	.25		
		Total Design Review	56	90	.35	90	.12
		Preliminary	32	39	.26		
		Advanced Final	24	78	.27		
		Total Design Delay	210	221	.87	219	.15
		Project Start	179	189	.81		
		Before Preliminary	19	68	.46		
		Before Adv Final	12	33	.26		
200	X	Total Design Time	422	287			
		Project Start Delay	179	189	.81		
		Study and Delay	29	86	.37		
		Prelim, Review, Delay	91	93	.46		
		Adv Fin, Review, Final	123	110	.55		
180		Total Design Time	455	279			
	X	Project Start Delay	199	188	.80	189	.09
21		Total Design Time	416	161	.63		
		Study and Delay	182	119	.63	115	.39
	X	Study Design	97	95	.23 .68		
		Delay Before Prelim	85	88	.60 .61		
130		Total Design Time	468	290	.53		
		Prelim, Review, Delay	140	81	.53	77	.33
	X	Preliminary Design	72	58	.43 .69		
		Preliminary Review	49	39	.20 .51		
		Delay Before Adv Fin	19	40	.26 .53		
176		Total Design Time	449	274	.51		
		Adv Fin, Review, Final	134	83	.51	77	.38
	X	Adv Final Design	88	54	.50 .64		
		Adv Final Review	22	38	.19 .60		
		Final Design	24	41	.19 .62		
97		Total Design Time	501	212			
	X	Final Design	44	45	.19	45	.28
93		Total Design Time	359	237			
	X	Advertisement, Award	127	69	.02	69	-.16

Table B4

Time and Cost Regression Results - Adjusted Costs - 79 District Engineer Projects

No. Projs	Dur ≠0	Total Design Time / Design Time Group / Design Period	Time vs. Time: Mean Days	Time vs. Time: Std Dev Days	Time vs. Time: Correl Coeff		Time vs. Cost: Std Dev Days	Time vs. Cost: Correl Coeff
79	X	Total Design Time	393	229			197	.55
		Total Active Design	206	147	.60		114	.66
		Study	16	58		.02		
		Preliminary	51	71		.45		
		Advanced Final	102	79		.36		
		Final	37	74		.36		
		Total Design Review	38	49	.60		46	.38
		Preliminary	20	41		.53		
		Advanced Final	18	34		.23		
		Total Design Delay	149	170	.65		171	.11
		Project Start	131	163		.58		
		Before Preliminary	10	32		.30		
		Before Adv Final	8	22		.34		
68	X	Total Design Time	393	229				
		Project Start Delay	131	163		.58		
		Study and Delay	26	68		.15		
		Prelim, Review, Delay	79	111		.55		
		Adv Fin, Review, Final	157	132		.48		
72		Total Design Time	422	218				
	X	Project Start Delay	144	165		.54	167	.06
14		Total Design Time	428	184		-.04		
		Study and Delay	128	106	-.04		115	.11
	X	Study Design	91	113	-.10	.94		
		Delay Before Prelim	37	39	.19	-.01		
33		Total Design Time	496	233		.65		
		Prelim, Review, Delay	189	93	.65		90	.32
	X	Preliminary Design	122	57	.37	.59		
		Preliminary Review	49	51	.59	.88		
		Delay Before Adv Fin	18	32	.31	.45		
73		Total Design Time	391	228		.54		
		Adv Fin, Review, Final	169	130	.54		120	.40
	X	Adv Final Design	111	76	.42	.65		
		Adv Final Review	20	35	.25	.57		
		Final Design	38	76	.38	.79		
34		Total Design Time	482	219				
	X	Final Design	84	94		.34	78	.59
42		Total Design Time	398	249				
	X	Advertisement, Award	92	67		-.18	68	-.13

Table B5

Time and Cost Regression Results - Adjusted Costs - 77 Nonoriginal Design Projects

No. Projs	Dur ≠0	Total Design Time / Design Time Group / Design Period	Time vs. Time: Mean Days	Time vs. Time: Std Dev Days	Time vs. Time: Correl Coeff	Time vs. Cost: Std Dev Days	Time vs. Cost: Correl Coeff
77	X	Total Design Time	397	288		273	.39
		Total Active Design	152	112	.44	83	.70
		Study	10	24	.80		
		Preliminary	55	64	.06		
		Advanced Final	66	53	.39		
		Final	21	56	.38		
		Total Design Review	39	46	.35	42	.44
		Preliminary	24	35	.31		
		Advanced Final	15	21	.25		
		Total Design Delay	206	255	.87	258	.03
		Project Start	168	244	.80		
		Before Preliminary	24	61	.21		
		Before Adv Final	14	45	.33		
77	X	Total Design Time	397	288			
		Project Start Delay	168	244	.80		
		Study and Delay	34	78	.20		
		Prelim, Review, Delay	93	99	.30		
		Adv Fin, Review, Final	102	98	.48		
60		Total Design Time	493	253			
	X	Project Start Delay	215	257	.79	254	.24
14		Total Design Time	468	160	.49		
		Study and Delay	169	85	.49	84	.42
	X	Study Design	54	30	.26 .30		
		Delay Before Prelim	115	81	.42 .94		
52		Total Design Time	366	259	.72		
		Prelim, Review, Delay	138	91	.72	80	.52
	X	Preliminary Design	82	62	.27 .66		
		Preliminary Review	36	37	.61 .57		
		Delay Before Adv Fin	20	53	.51 .55		
58		Total Design Time	487	251	.25		
		Adv Fin, Review, Final	136	90	.25	80	.49
	X	Adv Final Design	88	42	-.01 .56		
		Adv Final Review	19	23	.05 .55		
		Final Design	29	63	.36 .86		
32		Total Design Time	591	254			
	X	Final Design	52	77	.24	68	.52
32		Total Design Time	283	272			
	X	Advertisement, Award	96	36	-.21	35	-.31

Table B6

Time Regression Results - Adjusted Costs - Ratio of Time Standard Deviation to Mean Time

Total Design Time Design Time Group Design Period	285 (All) Projs	208 Original Des Proj	200 AE Projs	79 DE Projs	77 Non-Original Des Proj
Total Design Time	.67	.66	.68	.58	.73
Total Active Design	.67	.69	.66	.72	.74
Study	4.03	4.31	4.16	3.60	2.48
Preliminary	1.31	1.37	1.23	1.39	1.15
Advanced (or Early) Final	.77	.75	.75	.77	.80
Final	1.99	1.81	1.83	2.05	2.59
Total Design Review	1.61	1.66	1.62	1.28	1.20
Preliminary	1.41	1.40	1.22	2.00	1.42
Advanced (or Early) Final	3.12	3.21	3.29	1.85	1.47
Total Design Delay	1.13	1.09	1.05	1.14	1.23
Project Start	1.17	1.07	1.05	1.24	1.45
Before Preliminary	3.72	4.51	3.63	3.08	2.54
Before Advanced Final	2.87	2.46	2.77	3.03	3.21
Total Design Time	.67	.66	.68	.58	.73
Project Start Delay	1.17	1.07	1.05	1.24	1.45
Study and Delay	2.94	3.26	3.00	2.60	2.30
Preliminary, Review, Delay	1.15	1.19	1.03	1.41	1.06
Advanced Final, Review, Final	.88	.84	.89	.84	.96
Total Design Time	.60	.63	.61	.52	.51
Project Start Delay	1.06	1.01	.95	1.15	1.19
Total Design Time	.40	.43	.39	.44	.34
Study and Delay	.72	.87	.65	.83	.50
Study Design	1.07	1.01	.98	1.25	.55
Delay Before Preliminary	1.14	1.52	1.03	1.05	.70
Total Design Time	.59	.52	.62	.47	.70
Preliminary, Review, Delay	.57	.53	.58	.49	.66
Preliminary Design	.74	.73	.80	.47	.76
Preliminary Review	.84	.76	.78	1.05	1.02
Delay Before Advanced Final	2.07	1.67	2.15	1.74	2.58
Total Design Time	.63	.66	.61	.58	.52
Advanced Final, Review, Final	.70	.70	.62	.77	.67
Advanced Final Design	.66	.69	.61	.69	.48
Advanced Final Review	1.80	1.93	1.78	1.76	1.18
Final Design	1.88	1.78	1.69	2.01	2.19
Total Design Time	.46	.46	.42	.45	.43
Final Design	1.16	1.06	1.06	1.12	1.49
Total Design Time	.66	.58	.66	.63	.96
Advertisement and Award	.60	.62	.54	.73	.38

Table B7

Time and Cost Regression Results - Adjusted Costs -
Time and Cost Comparisons

	Total Design Time, Cost Criteria	Mean Days	Std Dev Days	Mean Dollars	Std Dev Dollars
285	(All) Projects	421	283	57,079	71,879
	Project Start Delay Time ≠ 0	456	275	59,847	73,276
	Study Design Time ≠ 0	421	168	58,570	65,571
	Preliminary Design Time ≠ 0	473	279	69,650	75,345
	Advanced Final Design Time ≠ 0	440	276	60,234	74,377
	Final Design Time ≠ 0	515	235	68,845	80,836
	Advertisement and Award Time ≠ 0	367	242	61,254	82,511
208	Original Design Projects	430	282	61,464	76,357
	Project Start Delay Time ≠ 0	445	280	61,424	76,643
	Study Design Time ≠ 0	389	169	46,312	43,352
	Preliminary Design Time ≠ 0	523	275	80,076	81,512
	Advanced Final Design Time ≠ 0	426	281	62,251	77,611
	Final Design Time ≠ 0	491	225	70,471	87,429
	Advertisement and Award Time ≠ 0	392	227	65,965	88,283
200	Architect-Engineer Projects	422	287	64,533	80,344
	Project Start Delay Time ≠ 0	455	279	66,856	81,838
	Study Design Time ≠ 0	416	161	64,109	75,588
	Preliminary Design Time ≠ 0	468	290	71,574	81,296
	Advanced Final Design Time ≠ 0	449	274	69,130	83,419
	Final Design Time ≠ 0	501	212	75,759	89,852
	Advertisement and Award Time ≠ 0	359	237	70,669	94,126
79	District Engineer Projects	393	229	41,446	42,447
	Project Start Delay Time ≠ 0	422	218	43,335	43,585
	Study Design Time ≠ 0	428	184	50,262	48,281
	Preliminary Design Time ≠ 0	496	233	62,072	44,964
	Advanced Final Design Time ≠ 0	391	228	42,602	43,664
	Final Design Time ≠ 0	482	219	55,031	48,966
	Advertisement and Award Time ≠ 0	398	249	43,121	44,789
77	Nonoriginal Design Projects	397	288	45,238	56,853
	Project Start Delay Time ≠ 0	493	253	53,159	61,146
	Study Design Time ≠ 0	468	160	76,958	88,016
	Preliminary Design Time ≠ 0	366	259	47,396	54,407
	Advanced Final Design Time ≠ 0	487	251	53,383	62,263
	Final Design Time ≠ 0	591	254	63,609	55,298
	Advertisement and Award Time ≠ 0	283	272	45,796	58,297

Table B8

Design Time (Days) Standard Deviation After Regression Removed
Variation in Design Time - Design Cost Equations

No. Projects Determining Curve	Number of Projects Fit to Curve				
	All 70	54 3-Phase	14 2-Phase	15 Building	5 Airfield
All 70	62	66	33	114	111
54 3-Phase	62	68			
14 2-Phase	361		32		
15 Building	72			112	
5 Airfield	277				18
Mean Time	198	213	142	379	212
Degrees of Freedom (Residual)	67	51	12,11	12	2

CERL DISTRIBUTION

Chief of Engineers
ATTN: DAEN-MCZ-S (2)
ATTN: DAEN-RD
ATTN: DAEN-MCC-C
ATTN: DAEN-MCE
ATTN: DAEN-MCP/Mr. Sheehey
Dept of the Army
WASH DC 20314

Defense Documentation Center
ATTN: TCA (12)
Cameron Station
Alexandria, VA 22314

Library of Congress (2)
Exchange and Gift Div
ATTN: American and British
WASH DC 20540

Defense Logistics Studies Information Exchange (2)
U.S. Army Logistics Management Center
ATTN: AMXMC-D
Ft Lee, VA 23801

Commander
U.S. Army Foreign Science and Technology Center
220 7th St, NE
Charlottesville, VA 22901

Engineer Studies Group/DAEN-FES
6500 Brooks Lane
WASH DC 20315